(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 111 575 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
27.06.2001 Bulletin 2001/26

(51) Int Cl.7: G09G 3/34, G09G 3/36

(21) Application number: 00122867.5

(22) Date of filing: 25.10.1995

(84) Designated Contracting States:
DE FR GB NL

(30) Priority: 25.10.1994 US 328375
22.02.1995 US 392055
03.03.1995 US 398292
23.07.1995 US 1972 P

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
95941333.7 / 0 789 852

(71) Applicant: Fergason, James L.
Atherton, CA 94027-3902 (US)

(72) Inventor: Fergason, James L.
Atherton, CA 94027-3902 (US)

(74) Representative: Crisp, David Norman et al
D. YOUNG & CO.
21 New Fetter Lane
London EC4A 1DA (GB)

Remarks:
This application was filed on 20 - 10 - 2000 as a divisional application to the application mentioned under INID code 62.

(54) Brightness control and halftoning in optical display system

(57) A display apparatus includes a passive display, a light source, and a video signal input, in operation in response to a video signal the passive display modulates light from the light source to provide an image, and the intensity of the light source is controlled by the video signal.

A method of producing a displayed image using a passive display illuminated by a light source is characterized in controlling the light source to obtain a displayed image with a desired amount of information, gray scale and/or color characteristics.

A method of reducing power consumption by a display system in which a light modulating display modulates incident light from a light source to provide images is characterized in controlling power provided to the light source to reduce output thereof for relatively dark images.

EP 1 111 575 A1

Description

CROSS REFERENCE TO RELATED PATENTS AND PATENT APPLICATIONS

[0001] Reference is made to commonly owned co-pending U.S. patent applications Serial No. 08/187,162, 08/187,050, and 08/187,163, filed January 25, 1994 (now, respectively, U.S. Patents Nos. 5,541,745 issued July 30, 1996, 5,532,854 issued July 2, 1996, and 5,717,422 issued February 10, 1998); Serial No. 08/275,907, filed July 5, 1994 (now U.S. Patent No. 5,519,524 issued May 21, 1996); Serial No. 08/328,375, filed October 25, 1994 (now U.S. Patent No. 5,537,256 issued July 16, 1996); Serial No. 08/392,055, filed February 22, 1995 (now U.S. Patent No. 5,572,341 issued November 5, 1996); Serial No. 08/398,292, filed March 3, 1995 (now U.S. Patent No. 5,715,029 issued February 3, 1998); Serial No. 08/295,383, filed August 24, 1994 (now U.S. Patent No. 5,621,572 issued April 15, 1997); Serial No. 08/328,371, filed October 25, 1994 (now U.S. Patent No. 5,858,589 issued September 15, 1998); Serial No. 08/383,466, filed February 3, 1995 (now U.S. Patent No. 5,606,458 issued February 5, 1997); and provisional patent applications Serial No. 60/002,780 entitled Optical system and method for a head mounted display providing both front and peripheral fields of view and Serial No. 60/002,779 entitled Monocular viewing device with retroreflector display system, telecommunication system, and method, both filed July 19, 1995. The entire disclosures thereof hereby are incorporated by reference.

TECHNICAL FIELD

[0002] The present invention relates generally, as is indicated, to optical display system and method, active and passive dithering using birefringence, color image superpositioning, and display enhancement with phase coordinated polarization switching. The present invention also relates to dithering systems for optical displays and methods, and, more particularly, to passive dithering systems and methods for changing the location of an optical signal and for improving an optical display. The present invention also relates to the enhancing of optical displays and methods to enhance such displays, and, more particularly, to enhancing optical displays and methods by coordinating the phase of switching light with the dynamic operation of the displayed image developing device.

BACKGROUND

[0003] The present invention may be used with various types of displays and systems. Exemplary displays are a liquid crystal display (sometimes referred to herein as "LCD"), especially those which modulate light transmitted therethrough, reflective liquid crystal displays, and so on.

[0004] Conventional optical displays typically display graphic visual information, such as computer generated graphics, and pictures generated from video signals, such as from a VCR, from a broadcast television signal, etc.; the pictures may be static or still or they may be moving pictures, as in a movie or in a cartoon, for example. Conventional displays also may present visual information of the alphanumeric type, such as numbers, letters, words, and/or other symbols (whether in the English language or in another language). Visual information viewed by a person (or by a machine or detector) usually is in the form of visible light. Such visible light is referred to as a light signal or an optical signal. The term optical signal with which the invention may be used includes visible light, infrared light, and ultraviolet light, the latter two sometimes being referred to as electromagnetic radiation rather than light. The optical signal may be in the form of a single light ray, a light beam made up of a plurality of light rays, a light signal such as a logic one or a logic zero signal used in an optical computer, for example, or the above-mentioned alphanumeric or graphics type display. Thus, as the invention is described herein, it is useful with optical signals of various types used for various purposes. Therefore, in the present invention reference to optical signal, light ray, light beam, light signal, visual information, etc., may be used generally equivalently and interchangeably.

[0005] In an exemplary liquid crystal display sometimes referred to as an image source, there usually are a plurality of picture elements, sometimes referred to as pixels or pels, and these pixels can be selectively operated to produce a visual output in the form of a picture, alphanumeric information, etc. Various techniques are used to provide signals to the pixels. One technique is to use a common electrode on one plate of a liquid crystal cell which forms the display and an active matrix electrode array, such as that formed by thin film transistors (TFT), on the other plate of the liquid crystal cell. Various techniques are used to provide electrical signals to the TFT array to cause a particular type of optical output from respective pixels. Another technique to provide signals to the pixels is to use two arrays of crossed electrodes on respective substrates of an LCD; by applying or not applying a voltage or electric field between a pair of crossed electrodes, a particular optical output can be obtained.

[0006] One factor in determining resolution of a liquid crystal display is the number of pixels per unit area of the liquid crystal display. For example, Sony Corporation recently announced a 1.35 inch diagonal high resolution liquid crystal display which has 513,000 pixels arranged in 480 rows of 1,068 pixels per row.

[0007] The picture elements (pixels or pels) may be discrete pixels, blocks or areas where an optical signal can be developed by emission, reflection, transmission, etc. such as the numerous pixels in the miniature image source of Sony Corporation mentioned above. The optical signal referred to may mean that light is "on" or provided as an output from the device, or that the pixel has its other condition of not producing or providing a light output, e.g., "off"; and the optical signal also may be various brightnesses of light or shades of gray. Alternatively, the optical output or optical signal produced by a pixel may be a color or light of a particular color.

[0008] The pixels may be a plurality of blocks or dots arranged in a number of lines or may be a number of blocks or dots randomly located or grouped in a pattern on the display or image source (source of the optical signal). The pixels may be a number of lines or locations along the raster lines that are scanned in a CRT type device or the pixels may be one or a group of phosphor dots or the like at particular locations, such as along a line in a CRT or other device. The optical signal produced by one or more pixels may be the delivery of light from that pixel or the non-delivery of light from th at pixel, or various brightnesses or shades of gray. To obtain operation of a pixel, for example, the pixel may be energized or not. In some devices energizing the pixel may cause the pixel to provide a light output, and in other devices the non-energizing of the pixel may cause the providing of a light output; and the other energized condition may cause the opposite light output condition. It also is possible that the nature of the light output may be dependent on the degree of energization of a pixel, such as by providing the pixel with a relatively low voltage or relatively high voltage to obtain respective optical output signals (on and off or off and on, respectively).

[0009] For example, in a conventional twisted nematic liquid crystal display device, polarized light is received by a liquid crystal cell, and depending on whether the liquid crystal cell receives or does not receive a satisfactory voltage input, the plane of polarization of the light output by the liquid crystal cell will or will not be rotated; and depending on that rotation (or not) and the relative alignment of an output analyzer, light will be transmitted or not. In an optical phase retardation device that has variable birefringence, such as those disclosed in U.S. Patents Nos. 4,385,806, 4,540,243, and RE.32,521 (sometimes referred to as surface mode liquid crystal cells), depending on the optical phase retardation provided by the liquid crystal cell, plane polarized light may be rotated, and the optical output can be determined as a function of the direction of the plane of polarization. In a CRT light emission or not and brightness may be determined by electrons incident on a phosphor at a pixel. In electroluminescent displays and plasma displays light output may be determined by electrical input at respective areas on pixels.

[0010] The interlacing of raster lines or display lines is a known practice used in television and in other types of display systems. For example, in NTSC and PAL television type cathode ray tube (CRT) displays it is known that two interlaced fields of horizontal lines are used to provide an entire image frame. First one raster or set of lines is scanned to cause one subframe (sometimes referred to as field) to be displayed; and then a second raster or set of lines is scanned to cause a second subframe (field) to be displayed. The electrical signals used to scan one line in one subframe and the electrical signals used to scan the relatively adjacent line of the subsequent subframe may be different, and, therefore, the optical outputs of those lines may be different. The two raster subframes are presented sufficiently fast that the eye of an observer usually cannot distinguish between the respective images of the two successive subframes but rather integrates the two subframes to see a composite image (sometimes referred to as a frame or picture). The two subframes are created sequentially by "writing" the image to respective pixels formed by phosphors to which an electron beam may be directed in response to electrical signals which control the electron beam in on-off and/or intensity manner. After the electron beam has reached the end of its scanning to create one subframe, e.g., the last pixel or phosphor dot area of that field, there is a period of time while the electron beam is moved or directed to the first pixel of the next subframe. During that period of time a blanking pulse is provided to prevent electrons from being directed to phosphors or pixels causing undesired light emission. Sometimes various circuits of a television or CRT display are synchronized to the operative timing of the television, CRT, etc. by synchronization with such blanking pulses.

[0011] The density of pixels, e.g., number of pixels per unit area, in a CRT display usually is, in a sense, an analog function depending on characteristics of the electron beam, drive and control circuitry for the beam, phosphor dot layout, shadow mask(s), etc., as is known. Usually a CRT is driven using the interlaced lines forming the subframes mentioned above. In an LCD, though, there is a fixed number of pixels per line or row; and data, e.g., whether a given pixel in a row is to transmit light or to block light transmission, usually is written to the pixels a row at a time. The data is written to one row, then to the next, and so on, and there usually is no interlacing of row s or of subframes as there is in CRT driving techniques.

[0012] In some LCD's the two subframes mentioned above usually are effectively averaged together, when driven by a CRT type of interlaced signal, since there usually is no physical interlacing of LCD pixels to form respective subframes as there are respective scan lines of phosphor dots, for example, in a CRT. Rather, the electrical signals for driving adjacent scan lines of different respective interlaced subframes of a CRT display, both usually are delivered to only a single row of pixels in an LCD. Each pixel responds to the electrical signal applied thereto to transmit or to block light, for example. Those two sets of electrical signals are applied to the row of pixels at different times. Therefore, at one time a given row of LCD pixels may present as an optical output optical information from one subframe and at a later time present optical information from the other subframe.

[0013] In a color display, such as a LCD (liquid crystal display), there usually are red, green and blue pixels which form a color triad (hereinafter referred to as triad). By operating the LCD in such a way that one or more of the pixels forming a triad provides (or produces) the respective color light of that pixel, different respective colors and white can be produced as output light. For example, if the red pixel of a triad were providing red output light; and the green and blue pixels were not providing output light, the light output from that triad would be red. Further, when two or more pixels of a triad are providing light output, a combination of those colors is seen by a person viewing (sometimes referred to as the viewer) the light output or image. The viewer usually visually superimposes the output light from the pixels of the triad; and the combined or superimposed lights therefrom provide the net effect or integrated light output of the triad. As an example, to produce a white light output from a triad, the red, green and blue pixels of that triad would provide, respectively, red, green and blue light; and those lights would be, in effect, superimposed by the viewer and seen as white light.

[0014] There is a continuing need and/or desire to improve resolution of displays.

[0015] In the above-mentioned patents are disclosed techniques for actively dithering, moving an optical signal, changing the location or optical path of an optical signal, etc. for several purposes, such as to increase resolution, to reduce jitter, and so on. There also are disclosed techniques for passive dithering, moving of optical signals, etc., for example to increase the fill factor of an image provided by a display by expanding the image or pixels forming the image.

[0016] An LCD using the twisted nematic effect usually cannot switch between transmission states as rapidly as changes occur in the applied electrical signal which operates the LCD. For example, the electrical input to a twisted nematic LCD can change nearly instantly, but it takes a number of milliseconds for the LCD to respond dynamically to the change in electrical input to change the optical response of the LCD.

[0017] The displaying of a dark scene using a display device (sometimes referred to as a passive display), which modulates light received from a separate light source, encounters a disadvantage which ordinarily is not present for displays which produce their own light, such as a cathode ray tube (CRT). The problem has to do with reduced resolution and/or contrast of the displayed image.

[0018] In a CRT, for example, when it is desired to display a dark scene, the intensity of the output light can be reduced. The different parts of the dark scene, then, all may be output at the reduced brightness or illuminance level. All pixels (e.g., picture elements, phosphor dots in a monochrome display or group of three red, green and blue phosphor dots for a multicolor display, etc.) of the CRT can be active so that resolution is maintained even though intensity of the light produced by the phosphors is reduced.

[0019] However, in a passive display device, such as a liquid crystal display, an electrochromic display, etc., whether of the light transmitting type or of the light reflecting type, the usual practice to reduce brightness of a displayed image or scene is to reduce the number of pixels which are transmitting light at a particular moment. Such a reduction reduces the resolution of the display. Also, such a reduction can reduce the contrast of the display.

[0020] The human eye has difficulty distinguishing between seeing or recognizing the difference between low and high brightness and contrast ranges. This difficulty is increased when the number of pixels is decreased and resolution is degraded.

[0021] It would be desirable to improve the contrast and resolution of passive displays.

[0022] In U.S. patent application Serial No. 08/187,163 (now U.S. Patent No. 5,717,422) is disclosed a passive apparatus, such as an LCD, and method for displaying images with high contrast by controlling the light input to the display to control brightness of the output while operating respective pixels of the display to obtain good contrast substantially without regard to the output brightness. Different color effects also are disclosed using, for example, field sequential switching of respective color light. However, this is another example of a passive optical device, in this case an LCD, in which field sequential switching could be improved if coordinated with the delays inherent in the dynamic optical response of a liquid crystal cell, for example, relative to the changes in operating signal, such as electric field, voltage, etc.

[0023] As is described in U.S. patent application Serial No. 08/187,163 (now U.S. Patent No. 5,717,422), an image of a candlelit room would be dim. In the prior art devices a relatively small number of pixels would be used, then, to transmit light to create the image, whereas a relatively large number of pixels would be used to block light transmission to give the effect of the reduced intensity or dim room. In the invention of such application, though, the number of pixels used to create the image remains constant, and the contrast ratio between one portion and another portion of the image remain constant; only the intensity of the illuminating light changes thereby to diminish the brightness of the room. Therefore, with the invention image data is not lost regardless of the brightness of the image, whereas in the prior art image data is lost because the additional pixels are used to brighten or darken the brightness of the image.

[0024] The features of the invention as described in that patent application can be used in a frame sequential basis. The features of the invention can be used regardless of whether the display is operated in reflective mode or in transmissive mode. Also, the features of the invention can be used in a virtual reality type display in order to provide a very wide range of contrast and of image brightness characteristics. The picture information is used to derive the brightness of the display, not the surrounding ambient. Using the invention of that application, the amount of information that can

be conveyed by the display is substantially increased over the prior art.

[0025] For example, if there were a grey scale of 100 shades of grey and a di splay with 10 shades of grey, the intensity of the illuminating source can be changed at 10 different levels, for example, and there also can be 10 different shades of grey provided by the display itself. Therefore, this provides 100 shades of grey. This characteristic can be increased by another factor of 10 by going to r, g, b (red, green, blue) modulation on a field sequential basis, which allows the possibility of 10 to the 6th different illumination levels and colors. The foregoing is especially important in head mounted displays where immersion in the image is extremely important. Using features of such patent application, there can be high illumination of the scene, then, the grey scale contrast ratio of the real image can be adjusted. As a result, there is a high contrast image presented in a bright motif. Another example using such invention is the ability to display a sunrise scene in which the red image is enhanced and the blue and green are minimized.

[0026] The invention of that application, then, can separate the two functions of brightness and image. The image is a function of the operation of the liquid crystal modulator and the illumination brightness is the function of the light source intensity. The r, g, b colors can be changed to give a candlelight or moonlight effect with good resolution and color function, but the brightness of the scene is a function of the background. As a result, it is possible to photograph the scene in daylight to get good contrast; and then by reducing the display illumination it is possible to give the impression of a moonlit or candlelit environment.

SUMMARY

[0027] With the foregoing in mind, then, one aspect of the invention is to increase the resolution of a display by electro-optically dithering an optical signal.

[0028] Another aspect is to increase the amount of data able to be displayed from a video signal or the like provided to a display system, such as an LCD display system or other display system.

[0029] As is described further below, the invention is useful to coordinate light output by an optical device, such as an LCD, for example, and the dynamic operation of such optical device with another optical device, such as one that switches or shifts the location of the output light for use, such as viewing, projection, etc., one that displays images in field (sometimes referred to as frame or part of a frame) sequential operation to present images with good contrast and/or color effect that are independent of the brightness of the output light, and so on.

[0030] One or more of these and other objects, features and advantages of the present invention are accomplished using the invention described and claimed below.

[0031] To the accomplishment of the foregoing and related ends, the invention, then, comprises the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative embodiments of the invention. These embodiments are indicative, however, of but a few of the various ways in which the principles of the invention may be employed.

[0032] Although the invention is shown and described with respect to certain preferred embodiments, it is obvious that equivalents and modifications will occur to others skilled in the art upon the reading and understanding of the specification. The present invention includes all such equivalents and modifications, and is limited only by the scope of the claims.

Brief Description of the Drawings

[0033] In the annexed drawings:

Fig. 1 is a schematic side elevation view of a CRT display including an electro-optical dithering system according to the present invention;

Fig. 2 is a schematic illustration of the components of the electro-optical dithering system of Fig. 1;

Fig. 3 is a schematic illustration of the double refraction effect through a calcite crystal which may be used in the electro-optical dithering system of the invention;

Figs. 4A, 4B and 4C are, respectively, schematic illustrations indicating exemplary axial alignment of the several components of the electro-optical dithering system shown in Fig. 2;

Figs. 5A and 5B are schematic illustrations of electro-optical dithering systems;

Fig. 6 is a schematic front view of the face or display output of a CRT showing exemplary raster lines;

Fig. 7 is a schematic plan view of part of a liquid crystal display showing areas where pixels are located and areas where there is circuit or dead space located between adjacent pixels and including the electro-optical dithering system of the invention;

Fig. 8 is a schematic top view of the display of Fig. 7 showing the paths of optical signals that are shifted in location according to the on or off state of the electro-optical dithering system of the display;

Figs. 9 and 10 are schematic block diagrams of synchronizing circuit techniques useful in the various display

systems of the invention;

Fig. 11 is a schematic illustration of part of a red, green and blue pixel arrangement for a multicolor display;

Fig. 12 is a schematic illustration of an alternate embodiment of optical display system using active and passive dithering system for displacing pixel images;

Fig. 13 is a schematic illustration of the locations of the original pixel images unshifted and of the shifted pixel images using the dithering system of Fig. 12 in four respective operations;

Fig. 14 is a schematic illustration of the display output from an optical display system of the type shown in Fig. 12, for example, showing shifting of pixel images relative to each other to obtain superpositioning of color pixel images and increased fill factor;

Figs. 15 and 16 are schematic illustrations of display outputs from an optical display system of the type shown in Fig. 12 and or in other figures hereof, for example, showing shifting of pixel images into gaps between pixels and in overlapping relative to each other;

Fig. 17 is a schematic illustration of the display output from an optical display system of the type shown in Fig. 18, for example, showing shifting of pixel images according to an exemplary prescribed pattern;

Fig. 18 is a schematic illustration of an optical display system including the components to obtain the operation depicted in Fig. 17 for a head mounted or boom mounted display system or other display system;

Fig. 19 is a schematic illustration of a display system in accordance with an embodiment of the invention including a head mounted portion;

Fig. 20 is a schematic section elevation view showing the various operational parts of the monocular viewing device used in the display system of Fig. 1;

Fig. 21 is a schematic illustration of a display optical system used in the viewing device of Figs. 19-20, for example, and/or in other viewing devices or display systems disclosed herein;

Fig. 22 is a schematic illustration of a light transmissive display system according to an embodiment of the invention;

Fig. 23 is a schematic illustration of a light reflective display system according to an embodiment of the invention;

Fig. 24 is a schematic view of a reflective field sequential display and illumination system using plural cholesteric liquid crystal reflectors and plural light sources of respective colors to provide a multicolor or full color display useful in various embodiments of the invention;

Fig. 25 is a schematic view of a head mounted display system including a pair of display subsystems in accordance with various embodiments of the invention; and

Figs. 26-31 are schematic graphical illustrations depicting operation of the invention.

DESCRIPTION

[0034] Referring, now in detail to the drawings wherein like reference numerals designate like parts in the several figures and initially to Fig. 1, an electro-optical dithering system in accordance with an embodiment of the present invention is generally indicated at 1 in use with a display 2 to form an optical display system 3 for providing optical signals, visual information, etc., as the output therefrom. The display 2 provides a source of light or optical signals, and such light is transmitted through the electro-optical dithering system to provide optical signals at respective locations for viewing or the like. Exemplary light is represented by an arrow 4, such as an optical signal produced at a particular location by the display 2 or produced by some oth er source and modulated by the display 2 as the output therefrom.

[0035] The location of the output optical signal 5 is represented by arrows 5a, 5b. Those arrows 5a, 5b represent the location of the output optical signal 5 resulting from the optical signal 4 being transmitted through the electro-optical dithering system 1 while the electro-optical dithering system is in a respective one or the other of the operative states thereof, such as off or on.

[0036] In the embodiment illustrated in Fig. 1 the display 2 is a CRT. It will be appreciated that the display 2 may be an LCD or another display, such as an electroluminescent display, plasma display, flat panel display or other display.

[0037] Dithering may refer to the physical displacement of an image. An electro-optical dithering system (EDS) refers to an electro-optical means to physically shift, translate or to change the location of an optical signal, such as an image. The image may be shifted along an axis from one location to another and then back to the first, e.g. up and then down, left and then right, etc. The optical signal may be moved in another direction along a straight or other axis or not along an axis at all. The dither ing may be repetitive or periodic or it may be asynchronous in moving an image from one location to another and then holding it there, at least for a set or non-predetermined time.

[0038] The electro-optical dithering system 1, as it is shown in Fig. 1, includes birefringent material, which sometimes is referred to as double refracting material, 10. An example of birefringent material is a calcite crystal material. Other double refracting (birefringent) materials also may be used. Birefringent material may transmit light straight through or may refract the light which is incident thereon, depending on a characteristic of the light incident thereon, such as optical polarization characteristic. In the illustrated embodiment the optical polarization characteristic is the direction

of the electric vector of plane polarized light. Plane polarized light having one direction of electric vector (sometimes referred to as direction of the polarization axis, the transmission axis of the polarizer or of the light, the plane of polarization of the light, the direction of polarization, etc.) may transmit directly through the birefringent material 10 without being refracted or bent, whereas light having a different direction of plane of polarization may be refracted (bent) by the birefringent material 10. For example, plane polarized light which encounters one index of refraction characteristic, such as an ordinary index of refraction characteristic, of the birefringent material may be transmitted without refraction. However, plane polarized light which encounters a different index of refraction characteristic, such as the extraordinary index of refraction, of the birefringent material will bend or refract at the interface with the birefringent material, both upon entering and upon leaving the birefringent material. Therefore, in a sense the birefringent material 10 changes the direction of light transmitted through it, for example, as it changes the location of the output optical signal from location 5a to 5b.

[0039] In the optical display system 3 embodiment illustrated in Fig. 1 the electro-optical dithering system 1 also includes a switch 11 that can be operated to change the characteristic of light relevant to the birefringent material 10 to change the location of the output optical signal. In the exemplary embodiment of Fig. 1 refraction of light or transmission of light without refraction by the birefringent material 10 depends on the direction of polarization of plane polarized light incident on the birefringent material 10, and the switch 11 is able to switch the direction of polarization of such light incident on the birefringent material 10.

[0040] In the embodiment illustrated in Fig. 1 the switch 11 is a liquid crystal cell or liquid crystal shutter type device which is able to transmit light to the birefringent material 10 such that the light incident on the birefringent material has a plane of polarization that can be changed by the switch. Accordingly, if the switch is in one operative state or mode, the light incident on the birefringent material 10 may have a plane of polarization such that the output optical signal 5 occurs at the location of the arrow 5a, and with the switch 11 in a different state of energization the plane of polarization of the light incident on the birefringent material 10 can be changed (e.g., switched to an orthogonal direction to the first-mentioned plane) thereby to cause the output optical signal to occur at the location of the arrow 5b.

[0041] A linear polarizer (sometimes referred to as a plane polarizer) 12 is between the switch 11 and the CRT display 2. The light 4 provided by the display 2 is plane polarized by the polarizer 12. The direction of polarization in cooperation with one condition of the switch 11 will result in the light being transmitted directly through the birefringent material 10 without refraction so as to appear at location of arrow 5a. However, in response to the other condition of the switch 11, the light will be refracted by the birefringent material 10 so as to occur at the location of the arrow 5b.

[0042] With the foregoing in mind, then, it will be appreciated that the invention includes a material that can move the location of an output optical signal relative to the location of an incident (input) optical signal depending on a characteristic of the inciden t optical signal, such as the direction of plane polarized light. The electro-optical dithering system 1 of the invention includes birefringent, double refracting, or equivalent material and a means to switch or to discriminate the characteristic of the incident optical signal.

[0043] In the embodiment illustrated in Fig. 1, the light 4 from a CRT is unpolarized. The polarizer 12 gives the light a characteristic of linear (plane) polarization. The switch 11 can change the direction of polarization, e.g., the direction of the electric vector of the polarized light. The birefringent material provides the output optical signal at the location 5a, 5b, depending on the characteristic of the light incident on the birefringent material.

[0044] The switch 11 may be a liquid crystal cell or several liquid crystal cells, such as twisted nematic liquid crystal cells, birefringent liquid crystal cells, such as those disclosed in U.S. Patents Nos. 4,385,806, RE.32,521, and 4,540,243, the entire disclosures of which hereby are incorporated by reference. If desired, the liquid crystal cells may be arranged in optical series and operated as a push-pull arrangement to improve linearity of response, and/or for other purposes, for example, as is disclosed in one or more of the aforementioned patents. Other types of liquid crystal cells also may be used for the switch 11. Further, other types of devices that are able to switch the optical characteristic of light, such as the direction of plane polarization, etc., may be used for the switch 11; several examples include ferro-electric liquid crystal cells, variable optical retarders, PLZT devices, and so on.

[0045] An advantage to using a liquid crystal display (LCD) as the display 2 with the dithering system 1 is that the output light from an LCD usually already may have a characteristic of optical polarization, such as linear polarization. In such a case, the linear polarization characteristic provided by such displays may eliminate the need for a separate linear polarizer 12.

[0046] In Fig. 2 the electro-optical dithering system 1 is shown in use in an optical display system 13 having a transmissive LCD 20. The LCD 20 may be a twisted nematic liquid crystal display, birefringent liquid crystal display, or some other type of liquid crystal display which produces in response to input light 21 from a light source 22, output light represented by an arrow 23. The LCD 20 may be transmissive or reflective. The output light 23 may be, for example, a graphic image, one or more light beams that are selectively turned on or off depending on operation of the liquid crystal display 20, etc. The graphic image may be a moving image, an alphanumeric display, etc. The dithering system 1 includes a birefringent material 10 and a switch 11. To simplify the following description, the switch 11 may be referred to as a polarization rotator, which rotates the plane of polarization of the light represented by arrow 23 an amount

depending upon the energization state or condition of the polarization rotator. For example, if the switch 11 were a twisted nematic liquid crystal cell, when it is deenergized, it would rotate the plane of polarization by 90 degrees (or some other amount depending on the nature of the liquid crystal cell), and when the twisted nematic liquid crystal cell is in a fully energized condition, it would not rotate the plane of p olarization of the light incident thereon. Similar operation could be obtained by using birefringent liquid crystal cells. Additionally, if desired, compensation may be provided for residual retardation in a liquid crystal cell, whether of the birefringent or twisted nematic type; such compensation may be provided by a wave plate or the like, such as a quarter wave plate positioned in a particular orientation relative to the rub direction or axis of the liquid crystal cell used in the switch 11.

[0047] Further, a wave plate, such as a half wave plate, may be used to rotate the plane of polarization of light 23 so it is appropriately aligned with the optic axis (sometimes referred to herein as the rub direction, optical axis, or simply axis) of the switch 11. For example, if the switch 11 were a twisted nematic liquid crystal cell, the plane of polarization of the light 23 may be parallel or perpendicular to the rub direction of one of the plates of the liquid crystal cell. If the switch 11 were a birefringent liquid crystal cell, such as a surface mode cell or a pi-cell (e.g., as the above-mentioned patents or in U.S. patent No. 4,582,396, which is hereby incorporated by reference), the plane of polarization of light 23 may be at 45 degrees to the rub direction. In using a half wave plate to adjust plane of polarization, for example, the axis of the half wave plate would be aligned to one half the angular distance between the orientation of the plane of polarization of the light incident on the half wave plate and the angular orientation desired for the light output from the half wave plate.

[0048] Turning to Fig. 3, there is shown an example of birefringent material 10 in the form of the mineral calcite, also referred to as a calcite crystal 30. Unpolarized light 3 1 enters the calcite 30 at the left hand face 32 thereof. The light enters at a right angle to the face 32. The light 31 is resolved into two orthogonally polarized components 33, 34 in view of the birefringent nature of the calcite. The optical axis of the light components 33, 34 are oriented such that one component 33 has a plane of polarization or electric vector direction into and out of the plane of the drawing of Fig. 3, as is represented by the dots shown in Fig. 3, and such light 33 experiences an index of refraction change between the environment 35 outside the calcite 30 and the environment 36 inside the calcite 30. However, the axis of the calcite crystal 30 is at a right angle to the plane of polarization to the light 33, and, therefore, this components of light 33 travels through the calcite crystal 30 without deflection (refraction); sometimes this light is referred to herein as the undithered light.

[0049] The light component 34 is polarized vertically in the plane of the drawing of Fig. 3 and is represented by a double-headed arrow in the drawing. The light component 34 experiences a change in index of refraction as above; however, the light component 34 also encounters the calcite crystal axis at an angle which is other than a right angle. Therefore, the light component 34 is refracted and its path is deflected (direction is changed) as it enters and leaves the crystal on its travel through the crystal 30, as is shown in Fig. 3; sometimes this light is referred to herein as the dithered light. This property of refraction of one polarization component and no refraction of the other polarization component of light incident on a birefringent material sometimes is called double refraction, and it occurs in many materials. The amount of physical displacement between the light components 33, 34 where they exit the right hand face 37 of the calcite crystal 30 and become, respectively, output light 33a, 34a represented by arrows at locations 38a, 38b, respectively, depends on the thickness of the calcite crystal, indices of refraction of the calcite crystal and the external environment thereof, and the orientation of the optical axis of the specific material, as is known.

[0050] In the optical display system 3 of Fig. 1 in which the display 2 is a CRT and in the optical display system 13 of Fig. 2 which uses an LCD 20 the direction of polarization of light incident on the switch 11 and the orientation of the switch 11 may be related for optimal operation. In one example of the invention, the switch 11 is a birefringent liquid crystal cell (or a pair of them operating in push-pull manner), and such liquid crystal cell(s) has (have) an axis which sometimes is referred to as the rub direction, alignment direction, optic or optical axis, etc. of the liquid crystal cell. Using such a liquid crystal cell in the systems 3 or 13, for optimal operation the polarization direction (transmission direction axis of the polarizer 12 or of the LCD 20, for example) should be at 45 degrees relative to the axis of the switch 11. Additionally, preferably the projection of the axis of the calcite crystal 30 is oriented at 45 degrees to the axis of the switch 11. These relationships are depicted in Figs. 4A, 4B and 4C.

[0051] Briefly referring to Figs. 4A, 4B and 4C, the above-described relationships of axes is shown. In Fig. 4A the transmission axis of the polarizer 12 or the plane of polarization of light delivered by the liquid crystal display 20 or by CRT 2 and polarizer 12 is shown as horizontal at 40. However, such direction also may be vertical, because it is desired that the relationship between that axis and the axis of the liquid crystal cell(s) of the birefringent liquid crystal cell switch 11 be at a relative 45 degrees thereto. Such 45 degrees relationship is shown by the respective axes 41, 42 for the switch 11. In fact, such axes 41, 42 may represent the axis of one liquid crystal cell and the axis of a second liquid crystal cell, the two being arranged in optical series and being operated in push-pull fashion. The axes 43, 44 of the calcite crystal 30 are shown as horizontal and vertical. However, the vertical axis actually is tipped in or out of the plane of the drawing and it actually is the projection of that axes which would appear as vertical; alternatively or additionally the horizontal axis may be tipped. Such projection of the axes preferably is at 45 degrees to the axes 41, 42 of the

switch 11. The described relative orientation of the axes of the various components used in connection with the invention is exemplary, and it will be appreciated that other arrangements may be used to obtain a particular type of operation. However, in the ideal simplified case described herein, the relationship described may be employed. Also, it will be appreciated that compensation may be provided to adjust the effective orientation of a particular axis. Such compensation can be provided using a birefringent material, a wave plate, such as a quarter wave plate or another one, etc., as was mentioned above.

[0052] It will be appreciated that whether the axis of a birefringent switch 11 is at plus or minus 45 degrees, represented by the axis lines 41, 42, for example, and whether a respective axis 43, 44 of the calcite 30 or other double refracting material 10 is at plus or minus 45 degrees to the axis of the birefringent switch (and parallel or perpendicular to the plane of polarization 40) will determine whether the dithered optical signal will be moved up, down, left or right relative to the undithered signal. If the switch 11 were a twisted nematic liquid crystal cell, the axis 40 may be parallel or perpendicular to one of the axes of the liquid crystal cell, and the orientation of the calcite 30 may be as shown in Fig 4C relative to the plane of polarization of the light represented at 40 in Fig. 4A.

[0053] It will be appreciated that the arrangement of axes herein described are exemplary. The alignment of the switch 11, whatever that component is comprised of, preferably is such that the switch is able to change a characteristic of light in the display system 3, 13 (and others described herein, for example) so that selective dithering can be carried out by a double refraction or other functionally equivalent material or device. Orientation of the double refracting material may be such as to cause such selective dithering depending on an optical characteristic of the light, which is incident thereon and/or is transmitted therethrough, relative to the double refracting material.

[0054] Quarter wave plates, other wave plates, etc. may be used in conjunction with coupling of light along optical paths used in the electro-optical dithering system 1 and/or the optical display systems 3 or 13, etc. Also, such wave plates may be used to convert plane polarized light to circularly polarize light or vice versa, depending on the nature of the optical coupling occurring in the various components and optical paths and/or the switch 11 used in the invention.

[0055] Briefly referring to Fig. 5A, the electro-optical dithering system 1 is shown having the light output 52 selectively switched between the location of the arrows 5a when the switch 11 is in the high voltage (no rotation of plane of polarization) state and the location of the arrow 5b, which occurs when the switch 11 is in the low voltage (polarization rotating) state. The light represented by arrow 5a is horizontally polarized, and the light represented by the arrow 5b is vertically polarized, as is represented in the drawing of Fig. 5A. By selectively energizing and de-energizing or, in any event, operating the switch 11 between two mentioned voltage states, which switch the polarization characteristic of the light, the location of the output optical signal 52 can be switched between the locations represented by arrows 5a and 5b.

[0056] A modified optical display system 60 is shown in Fig. 5B using an electro-optical dithering system 1, as was described above, in combination with an output polarizer (analyzer) 12'. The analyzer 12' may be a linear (plane) polarizer or some other device which can discriminate between the characteristics of light incident therein, such as the direction of plane of polarization, circular polarization, etc. The parts of the electro-optical dithering system 1 include a birefringent material 10, such as a calcite material described above, and a switch 11, such as one of the liquid crystal cell devices described above, or some other device, as will be appreciated.

[0057] The incident light 4 is received from a light source or image source, such as a CRT 2 or some other device that delivers unpolarized light output. Such unpolarized light 4 incident on the birefringent material 10 is divided into two components 61, 62. The light component 61 is horizontally polarized and it is transmitted directly through the birefringent material 10 without deflection or refraction. The light component 62 is polarized in the vertical direction, and it is refracted so that its direction is changed (path is deflected) in the manner shown representatively in Fig. 5B.

[0058] It will be appreciated that here and elsewhere in this description reference to directions is meant to be relative and exemplary; for example, horizontal and vertical are meant to indicate orthogonal relationship. Directions are exemplary and are used to facilitate description and understanding of the invention.

[0059] The horizontally polarized light component 61 and the vertically polarized light component 62, the directions of polarization being represented by the dots 63 and the arrow 64, respectively, are incident on the switch 11. From the switch 11 the light components 61, 62 are incident on the analyzer 12'. That light component which has a polarization direction that is parallel to the transmission axis of the analyzer 12' will be transmitted through the analyzer, and the other light component will be blocked. Depending on whether the switch 11 is in the operative state to transmit light without rotation of the plane of polarization or is in the operative mode to rotate the plane of polarization of the light transmitted therethrough, one or the other of the light components 61, 62 will be transmitted through the analyzer 12' at a respective location represented by one of the arrows 5a, 5b.

[0060] An exemplary use of the invention is illustrated in Fig. 7 for the CRT display 2 or for a liquid crystal display 20, for example. The display 2, 20 has a resolution of some fixed number of raster lines or rows of pixels that are updated periodically, for example, 60 times per second.

[0061] Assume that the speed of the display is increased, for example, is doubled to 120 times per second to rescan the raster lines and/or the rows of pixels. The switch 11 can be synchronized with the switching of the display

(CRT 2 or liquid crystal display 20) such that the raster images, for example, are alternately displaced and not displaced, e.g., to locations 5a and 5b, respectively. Such synchronization may be with respect to the blanking pulse or some other signal.

[0062] The amount of such shifting or displacement can be adjusted as aforesaid so that the displaced raster lines (or pixel rows) interdigitate the non-displaced raster lines (pixel rows). The information on the displaced and non-displaced rasters (pixel rows) are selected to carry complementary information; and, therefore, the resolution of the entire image displayed by the optical display system 3 or 13 is increased by a factor of 2. The same technique can be used to provide image coverage over the dead space between adjacent pixels in a liquid crystal display (or in a CRT, e.g., where a shadow mask blocks transmission of electrons) or to cover areas where conductors or other electrical connections or components of a liquid crystal display, such as parts of an active matrix array, are located, usually between adjacent pixels.

[0063] The display ordinarily would be refreshed or updated 60 times per second to cover both the odd and even raster lines. However, by increasing the refresh or update rate to 120 times per second and using the electro-optical dithering system to shift the location of the output image or optical signal for part of the time, essentially the odd and even raster lines, while unshifted, can be refreshed or updated 60 times per second and the odd and even raster lines, while shifted, can be refreshed or updated 60 times per second. The update or refresh times or rates presented here are exemplary; others may be used.

[0064] In Fig. 6, assuming the display 2 is a CRT, the front face 70 has a plurality of odd raster lines and a plurality of even raster lines. During operation of the CRT display 2, initially the odd raster lines are scanned to produce a first subframe (field). Subsequently, the even raster lines are scanned, and a second subframe (field) is produced. The information produced during the respective first and second subframes is referred to as complementary and together complete an image (sometimes referred to as a frame or picture) that is viewed. The time between producing one subframe and the next is sufficiently fast that the eye of an observer (viewer) integrates the respective firs t and second subframe images to see one complete (composite) image. Similarly, using the principles of the present invention, the space between adjacent raster lines can in effect be scanned to produce additional complementary image information. Thus, for example, the odd lines can be scanned during the first subframe; the even lines can be scanned during the second subframe; the odd lines can be scanned during a third subframe but during which the switch 11 of the electro-optical dithering system 1 is operative to cause shifting of the image to the space between respective adjacent pairs of odd and even raster lines; and finally during a fourth subframe analogous to the third, the even raster lines can be scanned while the electro-optical dithering system provides a shift of optical output, to produce the shifted image between respective pairs of odd and even raster lines. In this way resolution of the output image produced by the optical display system 3 is increased without having to increase the resolution or space between relatively adjacent raster lines (scan lines) of the CRT display 2 and a similar technique can be used to increase the effective number of the pixels, pixel rows, etc. to increase resolution of the liquid crystal display 20.

[0065] Referring to Figs. 7 and 8, a display system 99, which includes a liquid crystal display 100, is shown in top plan and top section views. The display system 99 is similar to the several other display systems described herein, such as those designated 3, 13, etc. The LCD 100 has a plurality of pixels 101 arranged in respective rows 102 with dead space 103 between respective rows and also at the edge 104 of the display 100. As is seen in Fig. 8, the liquid crystal display 100 includes a substrate 105 on which an active matrix array 106 is located. The liquid crystal display also includes a further substrate 107, a space 108 between substrates where liquid crystal material 109 is located, a seal 110 to close the space between the substrates, and (not shown) appropriate driving circuitry, as is well known. Light 120 represented by respective arrows illustrated in Fig. 8 is provided by a light source 121 and is selectively transmitted or not through the liquid crystal display. The light 120 is plane polarized by a plane polarizer 122 located between the light source 121 and the liquid crystal display 100, and the light 120 is transmitted or is not transmitted as a function of the plane of polarization thereof relative to an analyzer 123, as is well known. An electrode 124 on the substrate 107 and respective transistors and electrodes of the active matrix array 106 on the substrate 105 apply or do not apply electric field to liquid crystal material 109 at respective pixels 101 to determine whether or not the plane of polarization of light 120 is rotated and, thus, whether such light will be transmitted or will not be transmitted through the analyzer 123.

[0066] The light 120 which is transmitted through the analyzer 123 is incident on the electro-optical dithering system (EDS) 1. The electro-optical dithering system may be operated to not shift or to shift the location of the light 120 to locations 5a, 5b in the manner described above. If the optical signal at locations 5a, 5b is complementary, as was described above, the resolution of the optical display system 99 shown in Fig. 8 can be increased. Moreover, as part of such increased resolution, the dead space 103 where transistors 131 and/or other components that are not light transmissive in the active matrix array 106 effectively are covered over by the shifted light 5b, for example. Therefore, using the electro-optical dithering system 1 in a display system 99 as described, the light blocking portions of the active matrix array, of conductors, etc., can be in effect be overcome or negated while the overall resolution of the display is improved.

[0067] The parts shown in Figs. 7 and 8 are in a relatively horizontal relation showing dithering in a vertical direction. It will be appreciated that dithering can alternatively be in a horizontal direction or, if desired, multiple electro-optical dithering systems 1 can be used in optical series in order to obtain both vertical dithering and horizontal dithering.

[0068] The LCD 100 preferably is relatively fast acting to turn on and off. Therefore, using the combination of the fast acting LCD with the EDS 1 the respective lines of one subframe of information can be displayed by the respective rows of pixels of the LCD and subsequently the interlaced lines of the next subframe can be displayed by the same respective rows of pixels of the LCD.

[0069] The light source for the LCD 100 may be a pulsed source, which produces light output in pulses or sequential bursts. In such case, it is desirable to synchronize the light pulses or bursts of the light source with the LCD and/or with the EDS 1. Therefore, the respective pixels of the LCD would transmit or block light when the light source is producing a desired light output. The amount of time that the light source is transitioning between a light transmitting or light blocking state may be reduced and preferably is minimized. Also, the LCD would be operative to transmit or to block light when the light source is producing its intended light output rather than when the light source is not producing a burst of light or a desired light output. This tends to increase the contrast of the output image, since the shutter element (LCD 100) is not changing state when the light is pulsed, e.g. is changing its state from light producing to not producing or vice versa.

[0070] The EDS 1 and the LCD 100 preferably are synchronized. Therefore, when the LCD is producing scan lines of information from one subframe the EDS is in one state, and when the LCD is producing scan lines of information from the other subframe, the EDS is in its other state thereby causing the lines of one subframe to be interlaced with the lines of the other subframe. The EDS and a pulsating type light source also may be synchronized so that the EDS switches states during the time that no light output or non-optimal light output is produced by the light source. This further enhances contrast of the display system 3, 13, 99.

[0071] Various circuitry may be used to obtain the aforementioned synchronization. Two examples are shown, respectively, in Figs. 9 and 10. In Fig. 9 an exemplary display system 140 is shown. In the display system 140 a blanking pulse from a source 141 is supplied to respective LCD buffer and EDS buffer circuits 142, 143 to synchronize operation of them. The actual information signals from line 144 indicating the light transmitting or blocking state, for example, of the pixels of the LCD 100, for example, as is shown in Figs. 7 and 8, are provided the LCD buffer 142. Those information signals are not delivered to the LCD 100, though, until appropriately coordinated or synchronized with the blanking pulses. The EDS 1 is connected to the EDS buffer 143 and receives its drive signal from line 145 to dither or not the optical output from the LCD 100. The EDS buffer also receives the blanking pulse from the source 141 to synchronize delivery of the signals to the EDS with such blanking pulses and/or with the operation of the LCD buffer and information signals delivered to the LCD. The buffers 142, 143 can be synchronized with respect to each other by appropriate timed operation thereof with respect to the blanking pulse; or, alternatively, the buffers can be directly coupled to each other to synchronize operation thereof so that the dithering function is coordinated with switching of pixels or writing of information to the LCD.

[0072] As another example of synchronization, Fig. 10 depicts a display system 150 in which a pulsed light source 121, for example, receives pulsed power from a power supply 151. A signal representing the characteristics of the pulsed power from the powers supply 151 is provided to the LCD buffer 142 and EDS buffer 143, which respectively receive information and power signals on lines 144, 145 as described above. By synchronizing the LCD 100 and EDS 1 with respect to each other and/or with respect to the pulsing light source, the LCD can switch states as new information is written thereto when the light source is not producing significant light output, and/or the EDS can switch from direct transmission to dithered transmission of light states when the light source is not producing a bright output and/or the LCD is not in the process of switchin g display states.

[0073] The foregoing are but two examples of synchronization useful in the various display systems and embodiments of the invention. It will be appreciated by those having ordinary skill in the art that many other types of synchronizing techniques may be used to obtain the desired synchronization.

[0074] The EDS 1, 201 may be used in a display system 3, 13, 99, etc. which is monochrome or multicolor. Operation for a monochrome display system would be, for example, as is described above. One embodiment exemplifying operation for a multicolor, such as a red, green and blue (rgb), display system can employ the above-described type of operation for each color. Therefore, when one color or a group of colors is being displayed by respective pixels of such a color display, the optical signal output can be either transmitted without displacement or with displacement in the manner described above. As is depicted schematically in Fig. 11, part of a display 202', *e.g.*, similar to display 202, is shown including three representative adjacent pixel triads 281, 282, 283, each including a red, green and blue pixel portion. The display 202' may be operated in a color frame sequential mode in which respective red, green and blue frames or images are produced in time sequence. In this case all red pixels of respective pixel triads 281, 282, 283, etc. would be red where it is desired in the final image to have red light; subsequently green and then blue pixels of the image would be created. Alternatively, the respective red, green and blue pixels of respective triads can be displaying respective colors simultaneously. In either case, the principles of the invention using the EDS 1, 101, etc. may

be used to increase resolution of the output image in the above-described manner.

[0075] However, the EDS may be used for the purpose of selectively dithering (displacing) less than all of the color frames of a multicolor display, especially if the display is operated in a color frame sequential mode. For example, the dithering function can be used selectively to displace or not the green optical signal (light produced during the green frame) of the display 3, 13, 99; however, the EDS may be used so it does not selectively to dither the optical signal during one or both of the other color frames. Since the human eye is more sensitive to green light than to red or blue light, a significant enhancement of the apparent resolution of the multicolor display can be achieved by only selectively dithering the green light optical signal. If desired, the green and red optical signals can be selectively dithered without selectively dithering the blue optical signal; and this will result in an even greater apparent resolution of the multicolor display than if only the green optical signal were selectively dithered. Since the human eye is not as sensitive to blue light as it is to red or green light, the fact that resolution of the blue light or blue frame component of the overall image is not enhanced by the dithering of the invention may not significantly reduce the resolution of the composite multicolor output image. By reducing the amount of dithering required, it is possible that the complexity and/or cost of the electronic drive and timing circuitry employed in the invention can be reduced.

[0076] From the foregoing it will be appreciated that various embodiments of the invention using principles described herein may be employed with polarized light or unpolarized light. If possible to operate based on an unpolarized light as an input to the dithering system, e.g., using an NCAP display, there is no need for a polarizer and the undesirable effect that a polarizer has in blocking approximately 50% of the transmitted light.

[0077] Referring to Figs. 12 and 13 and the Chart I below, an optical display system 640, which includes two active dithering systems 641, 642 and one passive dithering system 643 is illustrated. The optical system 640 receives plane polarized light input 644 from a display 645. If the display 645 is not the type that provides a plane polarized light output, than an additional polarizer 646 may be used to provide such plane polarization. The orientation of respective components of the display system 640 is depicted by respective double-headed arrows above the various components.

[0078] The display system 640 may be used to provide a video output display operation. In an exemplary video display system, such as an NTSC or PAL system, it is conventional to compose a picture or a frame from two interlaced and sequentially presented fields (sometimes referred to as sub-frames). The optical display is able to produce four output conditions and signals in the manner described below. Such four output conditions may correlate to two respective frames and the two respective fields in each frame in a video display system, such as a television system using a liquid crystal display or some other display as the image source. However, it will be appreciated that the four output conditions described below may be correlated with the operation of other types of display systems or with a video display system in a way different from the exemplary operation described below.

[0079] In the optical system 640 the active dithering system 641 includes a switch 650 and a birefringent device 651. The active dithering system 642 includes a switch 652 and a birefringent device 653. The passive dithering system 643 includes a quarter wave plate 654 and a third birefringent device or material 655. The first and second switches 650, 652 may be respective surface mode birefringent liquid crystal cells or some other switch as is described elsewhere herein. The first, second and third birefringent devices 651, 653, 655 may be calcite material or some other birefringent material having axis oriented generally in the manner illustrated and tipped in the manner described above.

[0080] In describing operation of the optical display system 640, reference is made to a pixel of the display and light representing that pixel. The passive dithering system 643 effectively doubles the size of the pixel received by it from the display 645 and via the respective active dithering systems 641, 642. Therefore, as is seen in Fig. 36, each pixel input to the passive dithering system 643 is shown in solid lines and the doubled image thereof is shown in dotted lines adjacent thereto. For example, the pixel provided the passive dithering system 643 for the first field of the first frame is represented at 660, and the dithered image 660' is shown adjacent thereto in dotted lines. The passive dithering system operates in the manner of the passive dithering systems described above, for example.

[0081] Referring to the Chart I below, at frame 1, field 1, the voltage or energization of the first switch 650 is low so that the switch rotates the plane of polarization of the input vertically polarized light to horizontally polarized light as the output therefrom; see the column labeled "polarization direction output 1" having the letter "H" representing such horizontal polarization. Delivery of that horizontally polarized light to the first calcite 651 results in no shift of location. Continuing in the first line for frame 1, field 1 in the Chart I below, the voltage of the second switch 652 is low, whereby that switch rotates the plane of polarization back to vertical, as is represented by the letter "V" in the column labeled polarization direction output 2; and, therefore, the second calcite member 653 does not shift the location of the pixel. When the vertically polarized light output from the second calcite 653 enters the quarter wave plate 654, such light is divided into horizontal and vertical polarized components; the vertically polarized component transmits through the third calcite material 655, and the horizontally polarized component is shifted horizontally thereby effectively doubling the size of the pixel and producing the image 660', as is represented in the last column of the table designated calcite 3 shifting and doubling in the horizontal direction the particular pixel.

[0082] The second field of the first frame, for example, each pixel of the second frame, is displaced vertically relative to the corresponding pixel of the first field of the first frame. The pixel 661 represents the location of such downwardly

vertically displaced pixel for the second field of the first frame when the display system is a video type using interlaced fields to produce a frame. The second line of the Chart I below shows the conditions of the surface mode switches 650, 652, both being at high voltage so as not to rotate the plane of polarization of light transmitted therethrough, the resulting vertical downward displacement caused by the first calcite 651, and the doubling of the pixel by the passive dithering system 643 to produce not only pixel 661 but also the dithered pixel 661'. In pixels 660, 660', the two digits one in each represent, respectively, first frame, first field; and in the pixels 661, 661', the digits one and two represent first frame, second field, respectively.

[0083] Lines three and four of the Chart I below represent conditions and shifting resulting from those conditions of the switches 650, 652, direction of plane of polarization, etc. as was described above with respect to the first two lines of the Chart I below in order to achieve pixels 662, 662' and 663, 663', the primed pixels representing the dithered images that doubles the effective size of the overall pixel, such as the doubled size 663 plus 663'. As was mentioned above, the amount of shifting or translating of a particular pixel may be a function of the birefringence and/or optical thickness of the respective birefringent device, such as the respective calcite plates 651, 653, 655. Also, in a conventional video system there usually is no horizontal interlacing. The two field of the second frame represented by pixels 662, 662', 663, 663' may represent images moved to fill optical dead space, images to effect super imposing respective colors, as is described further below, or some other purpose. The increasingly effective size of each pixel, such as by doubling it to increase pixel 660 to the effective size of the sum of pixels 660, 660', can be used to improve resolution by effectively covering optical dead space in the display. The vertical displacing of pixels can be used to cause a liquid crystal display to provide a true or more nearly true interlaced operation whereby a pixel presented in one field of a frame is presented at a different location when the second field of that same frame is produced.

[0084] An advantage to the use of a dithering system with a display, such as a liquid crystal display, wherein the location of a pixel in the output can be shifted even though the actual location of the pixel in the display itself, such as an LCD, remains fixed is that correct data can be used to drive the pixel to provide the desired image output with relatively accurate following of the video signal. In a conventional LCD used to provide a video output a particular pixel may average the two fields of a frame; the average is not an accurate representation of the data received from the video signal. However, using a dithering system in accordance with the present invention, a pixel of the LCD may be driven based on information from the video signal intended to drive that pixel for a particular field of a frame to provide a visual output from the display system, such as display system 640. Subsequently when the image output of the respective pixel is shifted so that it is in the location desired for the second field of the particular frame, the actual information from the video signal that ordinarily would be used, say in a CRT, for example, could be the information that is used to operate or to drive the pixel which then provides a relatively accurate output representative of the appropriate input signal.

[0085] Using the two active and one passive dithering systems of the optical display system 640 is it possible to obtain eight copies of the original image, if desired, namely that provided at pixel 660, for example. Such eight copies may be obtained for every field for every frame, if desired and, thus, provide a macro pixel effectively about eight times the size of the pixel 660. In another embodiment, the data picked off the incoming analog signal or other video signal that operates the pixel 660, e.g., to turn it on or off, may be selected at the appropriate time to drive the pixel 660; and subsequently the pixel 661 may be operated as a function of information picked off the incoming video or analog signal representing the desired operation of the pixel 661 for interlaced fields operation of a conventional NTS or PAL system. However, additionally, if desired, the information from the incoming signal also could be picked off to represent the on/off or intensity effect of a pixel presented at location of pixel 662 accurately to represent that pixel even though that pixel physically may not be in the display 645 but rather is represented by the pixel of the display 645 that produces pixel image 660 shifted to the location of pixel 662. In other words, in an exemplary LCD there may be two relatively adjacent pixels, and the information from the incoming video signal would be picked off from that video signal to drive the respective pixels at the appropriate times. However, there also may be information contained in the video signal that would represent a desired optical output from the optical display system 640 from a pixel located between the two mentioned pixels. The present invention allows the information from the video signal that would be used to drive such intermediate pixel to be delivered to the pixel of the display 645 that would produce pixel image 660 while the dithering systems in the optical display system 640 effect horizontal or lateral displacement of the optical output to a location where such intermediate pixel might otherwise appear in the output image from the optical display system 640. This operation can enhance the resolution provided by the optical display system 640 and the accuracy of representation of the information carried by the input video signal, etc.

Superimposed Color Operation

[0086] Referring to Fig. 14 there is a shown a layout of an exemplary group of red, green and blue pixels of an exemplary liquid crystal display. The pixels are arranged in respective parallel rows and columns. Capital letters represent the color of the pixel, e.g., whether the pixel will deliver output like that is red, green or blue. Portions of two

rows are shown.

[0087] In the viewing of a color liquid crystal display the eye of the viewer, i.e., a human eye, may receive light input from many different pixels, and the eye effectively integrates the light inputs. One way of considering such viewing is to analogize the adjacent pixels, which are extremely small, effectively being superimposed so that the light therefrom is superimposed. Therefore, the combination of red, green and blue light that is superimposed would provide a white light as seen by the viewer.

[0088] The various embodiments of dithering systems in accordance with the present invention, including those disclosed and equivalents thereof, may be used to effect real superimposing of respective pixels, thereby enhancing the color output or color response of a color liquid crystal display. Such superimposition is depicted in Fig. 14 and now is described. The two rows of pixels shown in Fig. 14 are portions of respective rows of pixels in a color liquid crystal display. In the first row shown there are five pixels of the indicated colors; and in the second row there also are five pixels of the indicated colors. The sequence of colors is red, green and blue in both rows, but the sequence is offset by one pixel one row to the other. Therefore, in the first (top) row the first pixel row, and in the second row the first pixel is green. The arrangement of pixels in Fig. 14 is exemplary. Many other types of arrangements of pixels may be used whether in parallel rows and columns in the manner shown, in a so called delta configuration or pattern wherein there is an offset of rows, such as in Fig. 17, etc.

[0089] Using the optical display system 640, for example, the red pixel Ra at the top left of Fig. 14 is duplicated by the passive dithering system 643 to produce a red pixel or ra, which is represented in dash lines. Operation of the first dithering system 641 produces a second copy of both those red pixels displaced downward to locations of dash red pixels designated ra'. Such operation of the first dithering system 641 is coordinated with the second dithering system 642 to effect such downward shift. Similarly, horizontal shifting of all four red pixels just mentioned, namely Ra, ra, and the two designated ra' to a horizontally shifted or laterally shifted place results in the red pixels represented by dash lines and designated ra", one of which is superimposed over the green pixel Ga and one of which is superimposed on the blue pixel Ba. Such shifting may occur in a time sequence that is sufficiently fast that the human eye does not perceive the various shifts. Additionally, such shifting occurs in a time sequence coordinated with the desired color output from the display as represented by the input video signals to the display so that the superimposed colors provide a good quality and accurate representation of the color output from the display intended as a result of the input video signal. Similarly to the just described shifting of the red pixel Ra, shifting of the green pixel Ga also occurs, and such shifted pixels are represented by dotted outline at pixel locations represented by Ga due to the passive dithering system 643, and the other shifted pixels represented by dotted lines labeled ga' and ga" resulting from coordinated operation of the active dithering systems 641, 642. Furthermore, similar operation occurs for the blue pixel Ba, which is represented by phantom lines at pixels or pixel locations designed ba, ba', and ba". The four blue pixels represented by respective designations ba' and ba" near the bottom of Fig. 14 would overly or be superimposed on other pixels which are not shown in order to simplify the drawing and description.

[0090] Briefly referring to Fig. 15, shifting of the red pixel R into respective gaps and also superimposed on other pixels is shown schematically and simply. Specifically, pixel R is doubled by the passive dithering system 643 of the optical display system 640 in Fig. 12, for example to provide pixel r. Both pixels R and r are duplicated al so at pixel image locations r' shown in Fig. 15 in the gap between respective parallel rows of actual pixels. Pixels R, r and r' also are duplicated to the right relative to the illustration of Fig. 15 as pixel images r", some of which are in the same gap as pixel images r' and one of which overlies or is superimposed on the green pixel G. Thus, it will be seen that the pixels can be shifted to various locations in the display to achieve the desired optical output.

[0091] As the display of Fig. 15 is operated as part of the optical display system 640 to duplicate pixel images and/or to translate pixel images, so, too, the display shown in Fig. 16 represents similar modified operation of the optical display system 640. In particular, in Fig. 16 lateral shifting occurs like that in Fig. 15; but in Fig. 16 the vertical shifting of images results in the shifted image overlying the gap between adjacent rows of pixels of the display 645 and also overlying at least a portion of the pixel of the display 645 which is vertically displaced beyond such gap between pixel rows. Placing the pixel image in a gap increases the fill factor of the display. As was mentioned above, the shifting may result in superimposing pixel images to achieve the superimposed color response described above. Also, if desired, the vertical shifting may result in a portion of the shifted pixel image still overlapping a portion of the image in the original row, such as the illustrated pixel R and shifted pixel image r' therebelow. Such superimposing of pixels may provide a desired type of visual output for the o ptical display system 340.

[0092] Briefly referring to Figs. 17 and 18, there is shown a delta design of pixel layout for a display in Fig. 17, such as an LCD 645 and the output images therefrom after transmitting through an optical display system 680, which includes one active dithering system 681 and two passive dithering systems 682, 683. The active dithering system 681 includes a switch, 684, such as a birefringent liquid crystal cell, and a calcite crystal 685 able to transmit an image or to shift the image vertically ½ pixel, depending on the direction of plane of polarization of light incident thereon. The passive dithering system 682 includes a half wave plate 686, which rotates the plane of polarization of incident light 45 degrees, and a second calcite crystal 687, which can transmit the incident pixel image and has a thickness, birefringence, axial

orientation and tipped to displace the image ½ triad pitch horizontally. The passive dithering system 683 includes a half wave plate 688, which rotates the plane of polarization of incident light 45 degrees, and a second calcite crystal 689, which can transmit the incident pixel image and has a thickness, birefringence and axial orientation and tip to be able to displace the image 1 pixel pitch horizontally.

[0093] The optical display system 680 and dithering systems 681, 682, 683 thereof are set up to effect shifting ½ triad pitch to the right; 1 pixel pitch left and ½ pixel vertical pitch down. This arrangement is represented by only the blue pixel Ba. In shifting that pixel ½ triad pitch to the right, pixel ba results. In shifting both pixel Ba and ba 1 pixel pitch to the left, two respective pixel images ba' are produced--one is superimposed over the green pixel G, and one is in the gap between the blue pixel Ba and the red pixel R horizontally adjacent to the blue pixel Ba. Such shifting provides both for filling the optically dead space and effecting a superimposing of respective color pixel images as was described above. The shifting of pixel images vertically to form the four pixel images ba" places some of those in the gaps between rows of pixels and some in superimposed relation to the same and/or other pixels or shifted pixel images.

[0094] Referring to Fig. 19, a person 704 is shown wearing a head mounted viewing system 705 in accordance with the present invention. The viewing system may be part of a virtual reality viewing system having one or more displays which are viewed by the person. The viewing system may be part of a telecommunications system, entertainment system, or some other device in which light, optical, etc. information can be presented for viewing, projecting, photographing, or other use. Exemplary systems in which the invention may be used are disclosed in the above-mentioned patent applications; of course there may be other uses, too.

[0095] The head mounted viewing system 705 includes a housing 705h in which the various components of the viewing system 705 are included, and a mounting device 705m, such as a strap, eyeglass or goggles type frame support structure, etc. The mounting device 705m mounts the housing 705h for support from the head of the individual 704 placing the viewing system 705 in position in front of one of the eyes for viewing of an image presented by the viewing system 705. Whether the viewing system 705 is hand held, head mounted, or otherwise supported, for example, from a pedestal, tripod, frame, etc., from a table, from the floor, from a console 9, etc., preferably the viewing system 705 and housing 705h thereof is relatively small and sufficiently lightweight to facilitate moving, transporting, mounting, and/or holding. If the viewing system 705 is to be hand held or head mounted, it especially should be relatively lightweight to avoid being a weight burden on the hand or head of the individual using the viewing system 705. Also, to facilitate holding the viewing system 705 manually or head mounting the viewing system, the viewing system 705 should be relatively small. An exemplary viewing system may be, for example, approximately 4 to 5 inches in height, approximately 2 to 3 inches wide, and approximately 1 ½ to 2 inches deep. These are exemplary only, and it will be appreciated that other dimensions may be used.

[0096] In using the viewing system 705 it may be head mounted, hand held, coupled to a control box, console or the like, for example, similar to the main body of the conventional telephone when used in a telecommunication system.

[0097] Turning to Fig. 20, the viewing system 705 is shown in detail as a monocular viewing system. The housing 705h includes a viewing portion 711 and a support portion 712. The viewing portion 711 is intended to be viewed by an eye 713 of a person 704 (Fig. 42), and the support portion 712 is intended to be held in the hand of that individual. As was mentioned above, a head mount 705m may be provided to support the viewing system 705 from the head of a person. Thus, the housing 705h may be hand held, supported by a strap, cap, temple piece as in eyeglasses, or otherwise mounted for viewing by a person.

[0098] The viewing system 705 includes an optical system 714 in the housing 705h. The optical system 714 includes an image source 715, such as an LCD, that provides images for viewing by the eye 713 through a viewing port 716. A viewing lens 717 (or group of lens) presents to the eye 713 an image which appears at a comfortable viewing distance, such as about 20 inches or more away. An image resolution enhancing device 718 (sometimes referred to as an optical line doubler or OLD, dithering device or system, EDS, etc.) optionally included in the optical system 714 may be used to enhance the resolution or other qualities of the image produced by the image source 715.

[0099] A number of optical components 720 are included in the optical system 714. The optical components include focusing optics 721 (sometimes referred to simply as "lens" or as projection optics or as a projector), a beam splitter 722, and one or more retroreflectors 723, 723'.

[0100] The image source 715 includes a display 724d and a source of incident light 724i. The light source illuminates the display 724d, and the display in turn presents images which can be projected for viewing by the eye 713, as will be described in greater detail below. It will be appreciated that other types of image sources may be used, examples being cathode ray tube displays, other liquid crystal displays, plasma displays, etc. Examples of several displays and light sources are presented in the above-referenced co-pending patent applications. A connection cable 728 provides electrical and/or optical signals and/or power to the optical system 714, and is particular to the image source 715 and OLD 718 to develop the above-mentioned images for viewing by the eye 713. A control system 729 is coupled to the cable to provide such electrical signals for controlling operation of the display system 705, as is described in further detail below.

[0101] Summarizing such controlled operation, though, the display 724d may be a twisted nematic liquid crystal

display, and the OLD 718 includes an optical switch, such as a surface mode liquid crystal cell, that switches polarization characteristics of light to cause the light output to viewed by the eye 713 to be, for example, of enhanced resolution, as is described further below. Therefore, the control system 729 provides signals to generate the image by the display 724d; and the control system 729 also controls the optical switch to effect a synchronization such that there is a phase or time delay between the signals to the twisted nematic LCD and the signals to the optical switch. Accordingly, the optical switch which operates at a different speed, e.g., faster or in shorter time than the twisted nematic LCD will be coordinated with the operation of the twisted nematic LCD to improve operation and optical output of the display system 705.

[0102] In Fig. 21 details of optical components of the optical system 714 of the display system 705 are shown. The optical components shown in Fig. 21 are similar to those included in the housing 705h of Fig. 20; however, in Fig. 21 the housing 705h and support 705m are not shown to facilitate illustrating the invention and to simplify the drawing.

[0103] The optical components 720 of the optical system 714 include focusing optics 721 (sometimes referred to simply as "lens" or as projection optics or as a projector), a beamsplitter 722 and retro-reflector 723. The display system 705 also may include an image source 715 (Fig. 20) which provides images or light having characteristics of an image and, if desired, may be part of the mentioned projector. An exemplary image source is a liquid crystal display, such as a small liquid crystal television having a cross-sectional display area on the order of about one square inch or less. As shown, the image source 715 includes a liquid crystal display 724d which modulates light from the light source 724i to form images for viewing by the eye 713. Alternatively, the image source may be separate and simply used to provide one or more images or light having image characteristics that can be provided by the viewing system 705, such as that shown in Fig. 1, or a head mounted display, sometimes referred to as HMD to the eye 713. Additional optical components of the optical system 714 may include linear polarizers, circular polarizers, wave plates, focusing elements, such as lenses or mirrors, prisms, filters, shutters, apertures, diaphragms, and/or other components that may be used to provide a particular type of output image for viewing by the eye 713. Examples of several embodiments using such additional optical components are described below with respect to other drawing figures.

[0104] The invention is useful with virtually any type of image source or display source. An example of such a display source is a compact flat panel display, and especially one utilizing a reflective liquid crystal display made from a single crystal silicon active matrix array.

[0105] In Fig. 21 the image source 715 displays an image 825, which is shown in the drawing as an arrow 826. The light 827 leaving the image source 724 represents an image or has characteristics of an image, and that light is collected by the focusing optics 721 of the optical system 714 of the display system 705 and travels to the beamsplitter 722. In Fig. 21 and in a number of the other drawing figures hereof the focusing optics 721 is represented as a single lens. However, it will be appreciated that the focusing optics 721 may include one or more other components, such as lenses, reflectors, filters, polarizers, wave plates, *etc.*

[0106] Although the image source(s) 715 is shown in Fig. 21 located relatively above the beamsplitter 722, the image source may alternatively be located below the beamsplitter as is shown in Fig. 2.

[0107] At least some of the light 827a incident on the beamsplitter 722 is reflected by the beamsplitter as light 827b toward the retro-reflector 723. The retro-reflector may be, for example, a screen made of retro-reflecting material. Exemplary retro-reflectors are well known. One example is that known as a corner reflector or a sheet having a plurality of corner reflectors. Another example is a material having plural glass beads or other refracting and/or reflecting devices on or in a support. An example of a retro-reflector is a film or sheet material having a plurality of corner cubes which material is sold by Reflexite Corporation of New Britain, Connecticut. Such material is available having about forty-seven thousand corner reflectors per square inch.

[0108] The light (light rays) 827c, which are shown as broken lines, are reflected by the retro-reflector 723 such that their path is exactly back along their direction of incidence on the retro-reflector. In this way some of the light rays 827c pass through the beamsplitter 722 and are directed toward a location in space designated 828 in the illustration of Fig. 21. The eye 713 of a viewer (person) can be placed approximately at location 828 to see the image, and the pupil and lens, individually and collectively designated 713a, of the eye, accordingly, are shown at that point. The lens 713a focuses the light incident thereon as an image on the retina of the eye 713.

[0109] The projection lens 720 projects light toward the retro-reflector 723 to cause a real image to be formed at the retro-reflector or in front or behind the retro-reflector. As is defined in Jenkins & White, *Fundamentals Of Optics*, McGraw-Hill, 1976, for example, using an exemplary projection lens, an image is real if it can be visible on a screen. The rays of light are actually brought to a focus in the plane of the image. A real image is formed when an object is placed beyond the focal plane of a lens; the real image is formed at the opposite side of the lens. If the object is moved closer to the focal plane of the lens, the image moves farther and is enlarged. In contrast, a virtual image occurs if an object is between the focal point of a lens and the lens itself.

[0110] In Fig. 21 the broken lines represent light rays which travel after reflection by the retro-reflector along the same or substantially the same path, but in the opposite direction to, respective incident light rays impinging on the retro-reflector. Thus, the retro-reflector 723 is part of a conjugate optics path 823a in which light incident thereon is

reflected in the same path and opposite direction as reflected light. The beamsplitter 722 directs light from the focusing optics 721 into that conjugate optics path and toward the retro-reflector; and the beamsplitter also passes light in the conjugate optics path from the retro-reflector to the output port 16 (Fig. 2) for viewing by the eye 713. The beamsplitter 722 and retro-reflector 723 cooperate as a conjugate optics system to provide that conjugate optics path.

[0111] Using the described conjugate optics path and system, relatively minimal amount of the light from the image source 724 and focusing optics 721 is lost and, conversely, relatively maximum amount of light is directed to the eye 713. Also, there is substantial accuracy of image and image resolution conveyed to the eye. Furthermore, especially if a relatively good quality retro-reflector is used so that the precise location at which the image 830 is in focus will not be critical, e.g., it can be behind or in front of the retro-reflector, the tolerance required for the relative positioning of the components of the optical system 714 is less severe. This makes the HMD display system 705 relatively robust and reliable.

[0112] In Fig. 21 the viewed image 830 is represented by an enlarged arrow 831. Such arrow 831 is shown in Fig. 21 as a magnified focused image of the image 825 from the image source 724. The image 830 may be in focus at or approximately at the retro-reflector 723, and this is especially desirable for good quality images to be provided the eye 713 when a relatively low quality retro-reflector is used. A low quality retro-reflector is one which has relatively low resolution or accuracy of reflecting light in a conjugate manner in the same path but opposite direction relative to the incident light. With a low or poor quality retro-reflector and the image not being focused at the retro-reflector, it is possible that too much light may be lost from the desired conjugate optics path back to the eye 713, and this can reduce the quality of the image seen. However, the image 830 may be in focus at another location or plane either behind the retro-reflector (relative to the eye) or in front of the retro-reflector, and this is easier to do while maintaining a good quality image for viewing when the retro-reflector is a good quality one. The better the retro-reflector, the more self-conjugating is the optical system 714 and the less the need to focus with precision at the retro-reflector.

[0113] Retro-reflector quality may be indicated by the radians of beam spread of light reflected. For example, a relatively good quality retro-reflector may have from zero or about zero radians of beam spread to a few milliradians of beam spread. The quality usually is considered as decreasing in proportion to increasing beam spread of reflected light.

[0114] In considering the brightness of the image seen by the viewer, the nature of the beamsplitter 722 plays a role. The light produced by the image source 724 may be polarized or unpolarized. If the beamsplitter 722 is of a non-polarizing type, then a balanced situation is to have 50% of the light incident on the beamsplitter 722 be reflected and 50% transmitted. Thus, of the light 827a incident on the beamsplitter 722, 50% is reflected and sent toward the retro-reflector screen 723 as light 827b. Of the reflected light 827c from the retro-reflector 723, 50% of the light will be transmitted through the beamsplitter 722 and will travel to the viewer's eye 713. This configuration of the optical components 720 of the display system 705 can transfer to the viewer's eye a maximum of 25% of the light produced by the image source 724. If desired, the beamsplitter 722 can be modified in ways that are well known to change the ratio of the reflected light to transmitted light thereby. Also, the beamsplitter 722 may include an anti-reflection coating so that all or an increased amount of the image comes from one side of the beamsplitter and thus to reduce the likelihood of a double image.

[0115] Since the optical system 714 of the display system 705 provides good resolution of the image and maintains the characteristics thereof, the image source can be a relatively inexpensive one that does not have to compensate for substantial loss of image quality that may occur in prior display systems. Furthermore, since a relatively large amount of the light provided by the image source 724 is provided to the eye 713 for viewing, *e.g.,* since the retro-reflector can virtually focus the light for viewing at the eye, additional brightness compensation for loss of light, as may be needed in prior display systems, especially portable, *e.g.,* hand held or head mounted, ordinarily would not be required.

[0116] For exemplary purposes, in Fig. 21 three light rays 840a, 840b, 840c (collectively 840) originating at the tip of the arrow 826 constitute a portion of the light 827. Three light rays schematically shown at 841a, 841b, 841c (collectively 841) also are examples of light emanating at the tail of the arrow 826. The light 827 has characteristics of the image 825 from or provided by or at the image source 715, and represented by the exemplary light rays 840 and 841, is focused by the focusing optics 721 onto the retro-reflector 723. The size of the image 830 seen as the arrow 831 on the retro-reflector 723 depends on the focal length of the focusing optics 721 and the distances between the image source 724 and the retro-reflector 723 from the focal points 843, 844 of the focusing optics 721. Thus, magnification can depend on such focal length. The image source 715 should be located relative to the focusing optics 721 such that an image can be focused, e.g., in focus as is shown in Fig. 47, at or approximately at the retro-reflector. For example, the image source 715 may be beyond the focal point 843 of the focusing optics 721, and the retro-reflector likewise preferably is beyond the focal point 844 of the focusing optics so that the image can be focused at the retro-reflector.

[0117] In the illustration of Fig. 21 the image 830 on the retro-reflector 723 is magnified relative to the size of the image at the image source display 724d; it does not have to be magnified. The image 830 may be the same size as

the image 825 or it may be smaller. Thus, although the image source display 724d may be relatively small and/or may provide a relatively small size image 825 at its output, the size of the image 830 viewed by the eye 713 may be different.

[0118] The optical system 714 is operable to place the image plane effectively at the retina of the viewer's eye 713. This is accomplished by effectively putting the plane of the eye lens (or pupil) 713a effectively at the position occupied by the focusing optics 721 relative to the source of the image provided to the focusing optics. In a sense the lens 721 is optically superimposed on the lens 713a of the eye 713.

[0119] The invention provides an optical system in which there are conjugate paths from a lens, such as focusing optics 714, which corresponds to the "lens means" of an optical sensor, *e.g.,* the eye 713. Stated in another way, the invention presents visual information or optical data with a wide field of view by taking the output from a lens (focusing optics 721) and reflecting the light back along a conjugate path toward a location corresponding to that of the same lens which was in the original path, but actually direct that reflected light onto the eye placed at such corresponding location. This is obtained by using the conjugate optics arrangement disclosed herein.

[0120] The human eye is most comfortable when viewing an image at a distance of about twenty inches, approximately at the distance at which one would place a book, document, *etc.* to be read. It is desirable that the final image as seen by the viewer be located at such distance, *e.g.,* approximately twenty inches from the pupil 713a of the eye. This can be accomplished in the manner, if desired, by adding an additional lens 717 (Fig. 20) or other optical system (not shown) between the beamsplitter 722 and the eye 713. Such lens may cause the person to see a virtual image behind the retro-reflector, as is described in several of the above patent applications. Although in many viewing devices further spacing between the eye and the optical component of the optical system nearest the eye may be desired to obtain desired eye relief, the use of the lens 717 at the indicated distance of about ½ to 1 inch from the eye usually is acceptable and reasonably comfortable because that is the approximate spacing of ordinary eye glasses to which people ordinarily relatively easily become accustomed.

[0121] The function of the lens 717 may be obtained by using a negative lens at the focusing optics 721.

[0122] Referring to Fig. 22, a light transmissive display system according to an embodiment of the invention is illustrated at 901. The display system 901 includes a light source 902, liquid crystal display 903, such as that shown at 724d in Fig. 20, optics 904, such as that shown at 714 in Fig. 20, for projection or viewing of the images created by the liquid crystal display, a computer control 905, such as the control 729 in Fig. 20, and an image signal source 906, which may be part of the control 905 or a separate source of video signals or other signals as may be appropriate. A photodetector 907 also may be included in the system 901.

[0123] The light source 902 may be one or more light emitting diodes, incandescent light source, fluorescent light source, light received via fiber optics or other means, a metal halide lamp, etc.

[0124] The liquid crystal display 903 may be a twisted nematic liquid crystal cell, a variable birefringence liquid crystal cell, a supertwist liquid crystal cell, or some other type or liquid crystal cell able to modulate light. The liquid crystal display 903 may include polarizers, wave plates, such as quarter wave plates or other wave plates, means for compensating for residual birefringence or for problems encountered during off axis viewing, etc. Other types of display devices which modulate light as a function of some type of controlled input can be used in place of the liquid crystal cell 903. Exemplary liquid crystal cells and display devices which may be used for the liquid crystal cell 903 are disclosed in U.S. patents Nos. 4,385,806, 4,436,376, 4,540,243, Re. 32,521, and 4,582,396, which disclose surface mode and pi-cell liquid crystal devices, and in concurrently filed, commonly owned U.S. patent APPLICATION Serial No. 08/187,050, entitled "Folded Variable Birefringent Liquid Crystal Apparatus" (now U.S. Patent No. 5,532,854 mentioned above).

[0125] The optics 904 may be one or more lenses separate from and/or included as part of the liquid crystal display for the purpose of providing an output image for viewing or for projection. If for viewing, such optics 904 may be one or more lenses which focus an image for close, e.g., as in a head mounted display of the heads up display type, virtual reality type or multimedia type, or far viewing, e.g., as in a slide viewer or a television. If for projection, such optics 904 may include projection optics which project an image formed by the display 903 onto a screen for transmissive viewing or reflective viewing.

[0126] The image signal source 906 may be a source of computer graphics signals, NTSC type television (video) signals, or other signals intended to produce an image on the display 903. Such signals are decoded in conventional manner by the computer control 905, for example, as is the case in many display systems, and in response to such decoding or deciphering, the computer control 905 (or some other appropriate control, circuit, etc.) operates the display 903 to produce desired images. If desired, the computer control 905 can operate the display 903 in sequential manner to produce multiple images in sequence while the display is being illuminated by only a single light source or color of light, e.g., a monochromatic type of operation. Exemplary operation of this type is summarized in the above '396 patent. Other exemplary types of operation of the computer control 905 include those employed in conventional liquid crystal display televisions of the hand-held or larger type and/or liquid crystal type computer monitors. Alternatively, the computer control can operate the display 903 in a field sequential or frame sequential manner whereby a particular image is formed in several parts; while one part is formed, the display is illuminated by light of one color; while another part

is formed, the display is illuminated by light of a different color; and so on. Using this field sequential type operation, multicolor images can be produced by the display system apparatus 901.

[0127] In a typical input signal to a television or liquid crystal television, there is information indicating brightness of the light to be transmitted (or reflected) at a particular pixel. The computer control 905 is operative to compute the brightness information of a particular image or scene and in response to such computation to control the intensity or brightness of the light source 902. While intensity or brightness of the light source is controlled in this manner, the computer control 905 operates the liquid crystal display 903 to modulate light without having to reduce the number of pixels used to transmit light. Therefore, the full number or a relatively large number of pixels can be used to form the image or scene even if the brightness of the scene as controlled by the controlled light source is relatively dark.

[0128] Information coming through from the image signal source 906 may indicate various levels of illumination. There usually is a blanking pulse and a data line pulse. The computer control 905 can take the integral of the data line electrically or an integ ral of the whole set of data (from all of the data lines of the scene) or all of the p ixels while electrically skipping the blanking. Based on that integral, the brightness of the light incident on the display 903 is controlled by the computer control 905. It will be appreciated that a person having ordinary skill in the art would be able to prepare an appropriate computer program to provide the integral functions and to use the results of such integration to provide brightness control for the light source 902.

[0129] From the foregoing, then, it will be appreciated that the apparatus 901, including the computer control 905, is operative to control or to adjust the brightness of a scene without degrading the contrast ratio. Thus, the same contrast ratio can be maintained while brightness of a scene or image is adjusted. For example, the same contrast ratio or substantially the same contrast ratio can be maintained by the apparatus 901, whether depicting a scene of a bright sunlit environment or of the inside of a dark cave. Therefore, the scene will have the appearance of illumination under natural illumination conditions.

[0130] The features of the invention described below can be used in virtually any passive display system.

[0131] Power requirements of the apparatus 901 can be reduced over prior display systems because the intensity of light produced by the source 902 is controlled to create dark images. In prior systems, though, the intensity of the light produced by the source was maintained substantially constant while the amount of light permitted to be transmitted through the passive display would be reduced to create a dark scene image.

[0132] In addition to controlling intensity of the light source 902 as a function of brightness of a scene, the computer control 905 also may be responsive to measurement or detection of the ambient environment in which the apparatus 901 is located. The brightness of such ambient environment may be detected by the photodetector 907. The photodetector 907 may be place in a room or elsewhere where the image created by the display 903 is to be viewed; and the brightness of the source 902 can be adjusted appropriately. For example, if the room is dark, it usually is desirable to reduce brightness of the source; and if the room is bright or the apparatus is being used in sunlight, the brightness of the source may be increased.

[0133] Turning to Fig. 23, a light reflective display system according to the invention is illustrated at 901'. The display system 901' includes a light source 902', liquid crystal display 903', optics 904' for projection or viewing of the images created by the liquid crystal display 903', a computer control 905', and an image signal source 906. A photodetector 907 also may be included in the system 901. The various parts of the display 903' and optics 904' may be the same or similar to those disclosed in the U.S. patent applications and patents referred to above. The light source 902' and display 903' may be of the type disclosed in concurrently filed, commonly owned U.S. patent application Serial No. 08/187,162, entitled "Illumination System For A Display" (now U.S. Patent No. 5,541,745 mentioned above).

[0134] For example, the light source 902' may include a source of circularly polarized light 902a' and a cholesteric liquid crystal reflector 908. The liquid crystal display 903' may be a reflective variable birefringence liquid crystal display device.

Full Color Frame Sequential Illumination System and Display.

[0135] Turning to Fig. 24 a full color display subsystem 919 including illumination system 920 is shown. However, in the display subsystem 919 the illumination system 920 includes several sources of light, each having a different wavelength. For example, three separate light sources 902r, 902g, 902b provide red, green and blue wavelength light, respectively, or light that is in respective wavelength bands or ranges that include red, green and blue, respectively. The light sources may be respective light emitting diodes or they may be other sources of red, green and blue light or other respective wavelengths of light, as may be desired for use in the display subsystem 919. The cholesteric liquid crystal reflector 908 is able to reflect green light; the reflector 908a is able to reflect red light; the reflector 908b is able to reflect blue light. Such reflection occurs when the circular polarization characteristic of the light is the same direction as the twist direction of the cholesteric liquid crystal material in the respective reflector. The reflectors 908, 908a, 908b are transparent to the other polarizations of incident light and to the other wavelengths of incident light.

[0136] The illumination system 920 is intended sequentially to illuminate the display 903', which may include a wave

plate, such as a quarter wave plate, (or respective portions of the display) with respective wavelengths of light. For example, for a period of time the display 903' (or portion thereof) is illuminated with red light; subsequently illumination is by either green or blue light; and still subsequently illumination is by the other of green or blue light. Such sequential illumination may be carried out sufficiently rapidly so that respective red, green and blue images created by the display 903' when illuminated by the respective colors of light are output from the display subsystem 961 and are integrated by the human eye. As a result, the human eye effectively sees a multicolor image. Other examples of frame sequential switching to provide multicolor and/or full color outputs are known in the art. Various advantages inure to a frame sequential multicolor display, including the ability to provide high resolution with approximately one-third the number of picture elements required for a full color r, g, b display system in which respective pixels are red, green or blue.

[0137] The sequential delivering of red, green and blue light to the display 903' is coordinated by the control system 905 with the driving of the display 903'. Therefore, when a red image or a portion of a red image is to be produced by the display 903', it is done when red light is incident on the display 903'; and the similar type of operation occurs with respect to green and blue images.

[0138] If the respective light sources 902r, 902g, 902b are light emitting diodes, they may be sequentially operated or energized to provide light in coordination with the operation of the display 903' under direct control and/or energization by the control system 905. Alternatively, the control system 905 may be coordinated with whatever other means are used to provide the respective red, green and blue color lights of the light source.

[0139] Another example of frame sequential or field sequential operation of a displays subsystem like that shown at 961 herein is described in the above-referenced patent applications. Another example of field sequential operation is described in U.S. patent No. 4,582,396, which is mentioned above and incorporated by reference.

[0140] Referring to Fig. 25, a head mounted display 960 includes a pair of display systems 961, 962 and a control system 705 for creating images intended to be viewed by the eyes 964, 965 of a person. The display systems 961, 962 may be positioned in relatively close proximity, for example, at approximately one inch distance, to the respective eyes 964, 965. A mounting mechanism, such as temple pieces 966, 967 and a nose bridge 968 may be provided to mount the display 960 on the head of the person.

[0141] The control system 905 in conjunction with the display systems 961, 962 are intended to create images for viewing by the eyes. Those images may be monochromatic. The images may be multicolor. The images may be two-dimensional or they may provide a three dimensional, stereoscopic effect. Stereoscopic effect viewing is obtained when the control system 905 operates the display systems 961, 962 to provide, respectively, right eye and left eye images that are sufficiently distinct to provide depth perception. Right eye, left eye imaging and depth perception are techniques used in some stereoscopic imaging and viewing systems which are commercially available.

[0142] The display systems 961, 962 may be identical. The control system 905 provides control and/or power input to the display systems 961, 962 to create images for display to the eyes 964, 965. The display 960 may be a head mounted display, such as a heads - up display, a virtual reality display, or a multimedia display. The control system 905 may be generally a control system of the type used in known head mounted displays to create such images. Such a control system may provide for control of color, light intensity, image generating, gamma, etc. The display systems 961, 962 may include focusing optics so as to focus the image created by the display systems for comfortable viewing, for example from a few inches up to a few feet in front of the eyes, say, from about 20 inches to about several feet in front of the eyes.

[0143] It will be appreciated that the features of the liquid crystal cell 903' may be used in the display 960 of the head mounted type. Also, features of the invention may also be employed in other types of display systems. One example is a display system that uses only a single display system of the type described herein. Such display system may be located in proximity to an eye for direct viewing. Alternatively, such display system may be used as part of a projection type display in which light from the display system is projected onto a surface where the image is formed for viewing. Various lenses and/other optical components may be used to direct from the display system light to create an appropriate image at a desired location.

[0144] Turning to Figs. 26-31, operation of the apparatus is described. In Fig. 26 a plan view of a dot matrix liquid crystal display is shown. The shade of grey measured at several pixels is indicated. According to the bottom graph in Fig. 26, the actual hade is shown; according to the dot matrix image at the side and top of Fig. 26, the actual shade of the pixel is shown. Thus, at location 1 on the graph at the bottom of Fig. 26, there is a shade 2. At location 2, there is a shade 1. At location 3 there is a shade 0, and so on. In pixel 1 marked in the top of Fig. 26, the pixel is a shade gray of 2; and at the adjacent pixel the pixel is a shade gray of 1, and so on. This is conventional. This would indicate the signals coming in to the computer control 905. In Fig. 27, an example of a bright image scene produced by back light at a medium (normal) illumination level is illustrated at the top; the shades of gray are shown at the middle left; and the lamp light level is constant at the bottom left. The viewer sees a bright/low contrast image of a person as seen at the top right of the drawing. A side view of the display representing respective pixels and the tray levels thereof is shown at the bottom right of the figure.

[0145] Fig. 28 is similar to Fig. 27 again with average constant lamp light level. The average light level is produced;

the average brightness output from the display is to be produced; and the viewer sees an average brightness high contrast image because all conditions are optimized.

[0146] Fig. 29 is similar to Fig. 27 again with average constant lamp light level and a dark transmission provided by the liquid crystal cell; the viewer sees a dim low contrast image.

[0147] Figs. 27-29 represent operation of a standard display apparatus. Figs. 30 and 31 represent applying the principles of the present invention to develop high contrast images. In Fig. 30 it is seen that there is the intent to produce a wide range of gray levels; and this is possible by using a high intensity lamp level; the result is a bright high contrast image. In Fig. 31 it is intended that the viewer see a dim image; the same range of grey shades are provided as is depicted in the middle left graph of the drawing; but the lamp level is low. Therefore, there is a good contrast ratio provide to the viewer; from 0 to about 7 at the brightness level shown in the graph at the upper left of the drawing.

CHART I

FRAME	FIELD	VOLT. SMD1	POL DIR OUT1	CALC1 SHIFT	VOLT SMD2	POL DIR OUT2	CALC2 SHIFT	1/4X POL DIR OUT÷2	CALC3 SHIFT DOUBLES HORIZ PIXEL
1	1	Lo	H	None	Lo	V	None	H,V	X 2
1	2	Hi	V	Vert. Down	Hi	V	Non	H,V	X 2
2	1	Lo	H	None	Hi	H	Horiz. Right	H,V	X 2
2	2	Hi	V	Vert. Down	Lo	H	Horiz. Right	H,V	X 2

C:\G\OPTI\OSVR\109.WO\109C_WO.FNL was

Claims

1. A display apparatus, comprising a passive display, a light source, and a video signal input, wherein in response to a video signal the passive display modulates light from the light source to provide an image, and characterized in that the intensity of the light source being controlled by the video signal.

2. The apparatus of claim 1, characterized in that the passive display comprises a liquid crystal display.

3. The apparatus of claims 1 or 2, characterized in that the passive display comprises a flat panel display.

4. The apparatus of claims 1-3, characterized in that the passive display is a video monitor.

5. The apparatus of claims 1 or 2, characterized in that the passive display is a projection display.

6. The apparatus of claim 4, further characterized in that the projection display includes projection optics.

7. The apparatus of claims 1-4, characterized in that the passive display is a direct view display.

8. The apparatus of claim 7, further characterized in comprising optics to provide the image for viewing from the direct view display.

9. The apparatus of claims 1-8, characterized in that the passive display does not produce its own illumination.

10. The apparatus of claims 1-9, wherein the light source is capable to provide plural colors of light to illuminate the display, and further characterized in comprising a control to control one or more of color, intensity, and gamma.

11. The apparatus of claim 10, further characterized in that the light source comprises plural light sources, at least two of which provide different color light.

12. A display apparatus in which light from a light source illuminates a display to provide an image, characterized in that the intensity of the light illuminating the display is controlled to adjust image brightness.

13. The apparatus of claims 1-12, wherein the intensity of the light is controlled to adjust image brightness without affecting contrast ratio and/or loss of image information.

14. The apparatus of claims 1-13, further characterized in that the light source is selected from the group comprising a light emitting diode light source, incandescent light source, flourescent light source, fiber optics, and a metal halide lamp.

15. The apparatus of claims 1-14, a, further characterized in comprising an image source to provide a video signal for the passive display, the image source including at least one of computer graphics signals and video signals.

16. The apparatus of claim 1-15, further characterized in that a computer is used to produce the desired images.

17. The apparatus of claims 1-11, further characterized in that a computer control responds to the brightness information for the displayed image and controls the light source output without having to change the number of pixels used to transmit light to obtain images of respective brightness and/or color.

18. The apparatus of claims 1-17, further characterized in that the light source is controlled to provide scenes having appearance as though illuminated under natural illumination conditions.

19. A method of producing a displayed image using a passive display illuminated by a light source, characterized in controlling the light source to obtain a displayed image with a desired amount of information, gray scale and/or color characteristics.

20. The method of claim 19, wherein the passive display has a limited number of discernible steps of brightness or gray scale, and further characterized in that the controlling of the light source increases the variation in brightness or gray scale of the displayed image.

21. A method of reducing power consumption by a display system in which a light modulating display modulates incident light from a light source to provide images, characterized in
controlling power provided to the light source to reduce output thereof for relatively dark images.

22. The method of claims 19-21, further characterized in controlling the light source to provide scenes having appearance as though illuminated under natural illumination conditions.

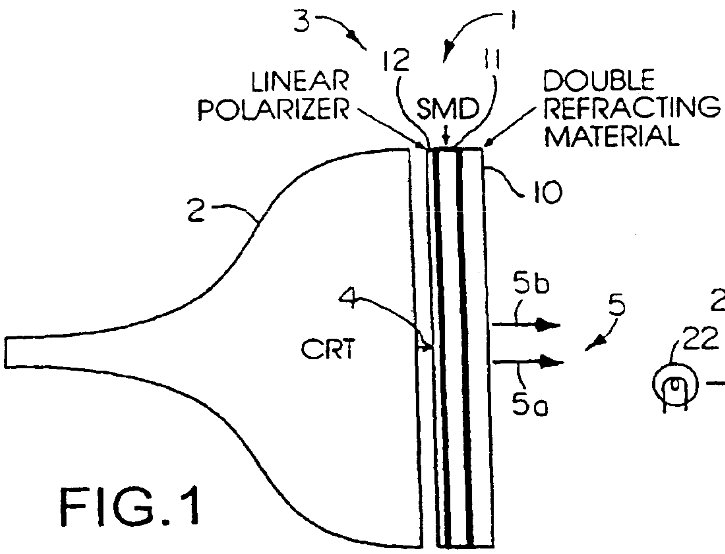

FIG.1

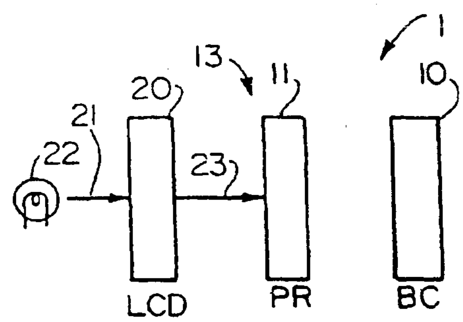

FIG.2

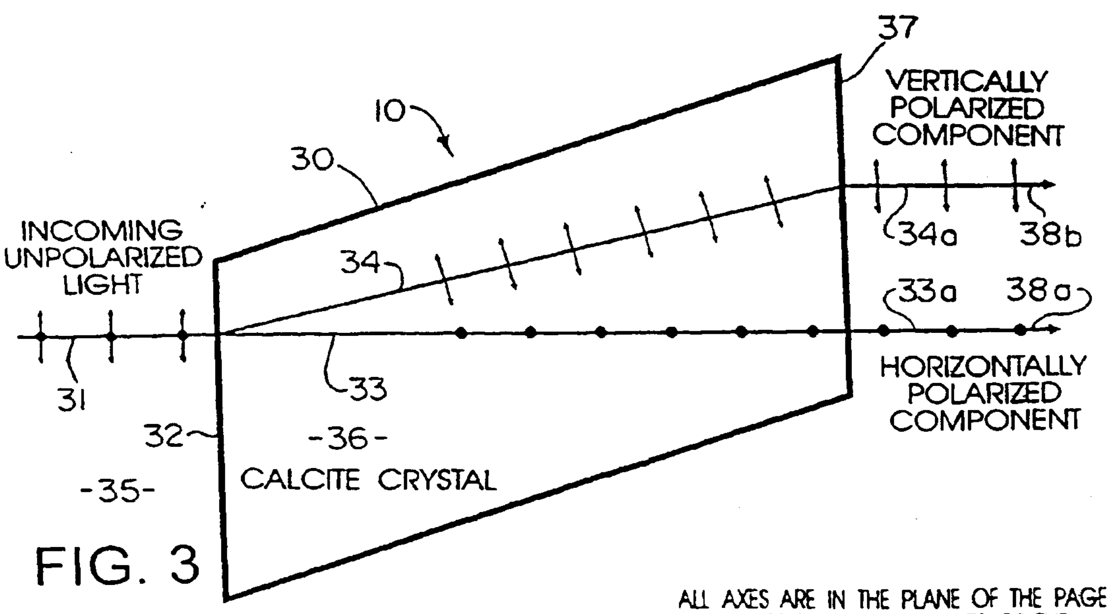

FIG. 3

ALL AXES ARE IN THE PLANE OF THE PAGE EXCEPT THE VERTICAL AXES OF THE DOUBLE REFRACTING MATERIAL WHICH TIPS IN/OUT OF THE PLANE OF THE PAGE

AXES OF THE COMPONENTS

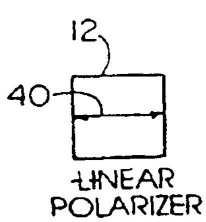

FIG.4A

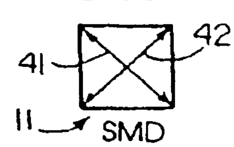

FIG. 4B

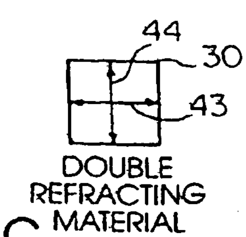

FIG. 4C

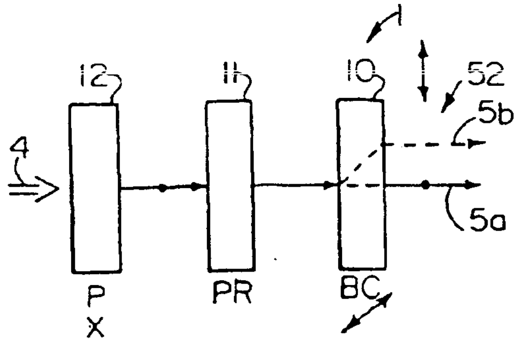

FIG. 5A

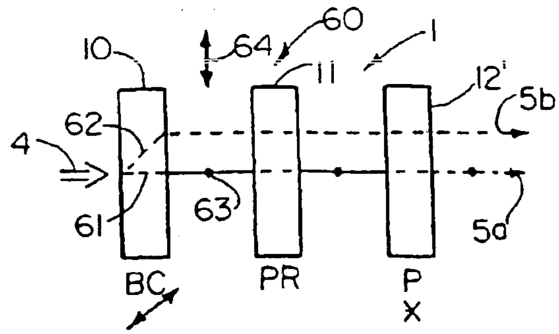

FIG. 5B

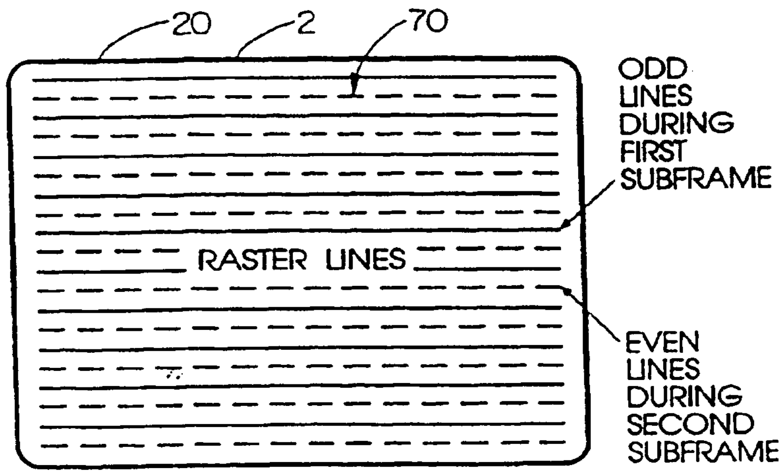

FIG. 6

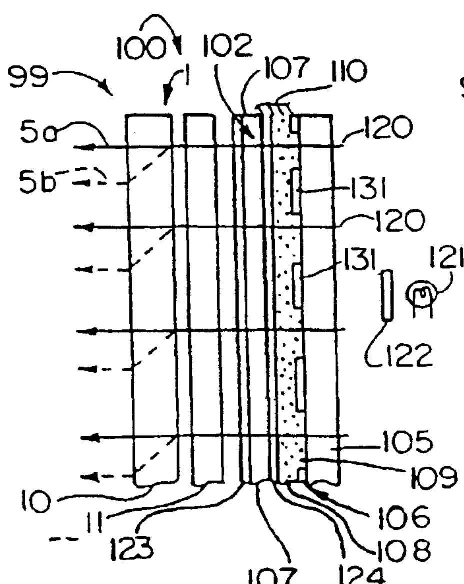

FIG. 8

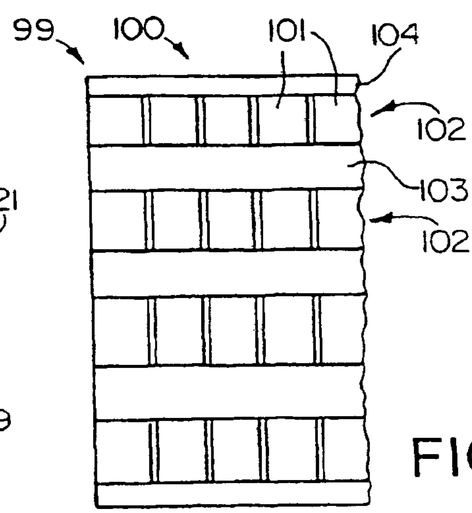

FIG. 7

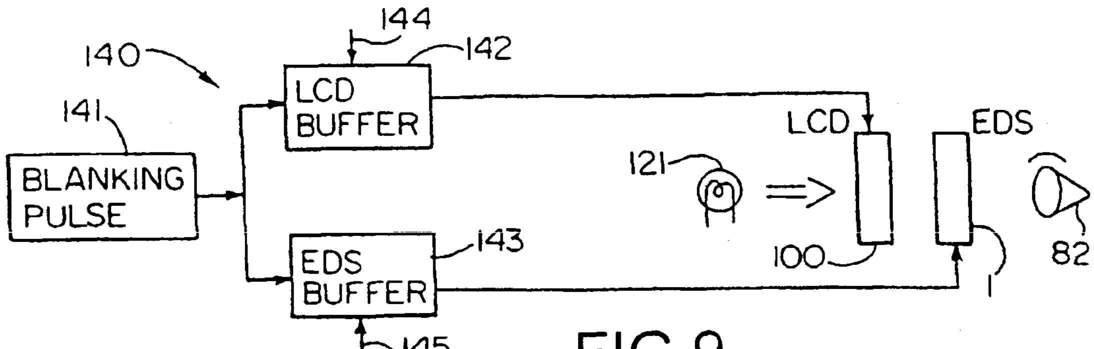

FIG.9

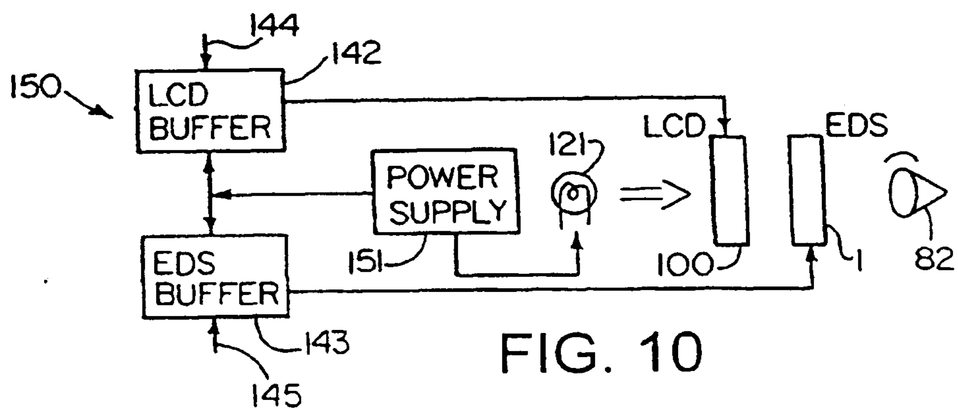

FIG. 10

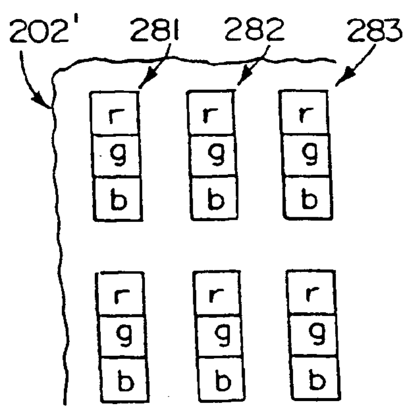

FIG. 11

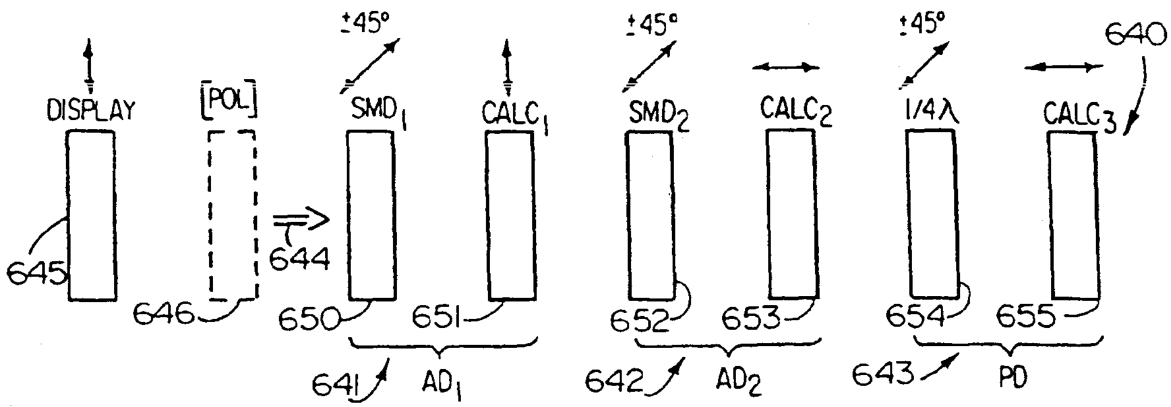

FIG. 12

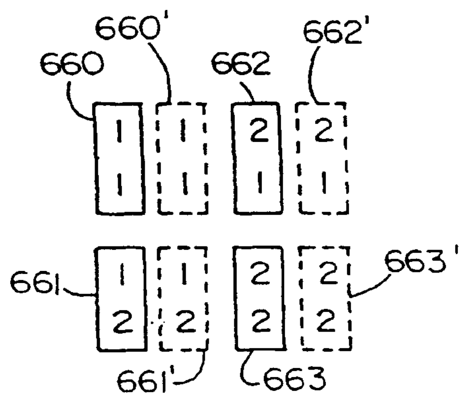

FIG. 13

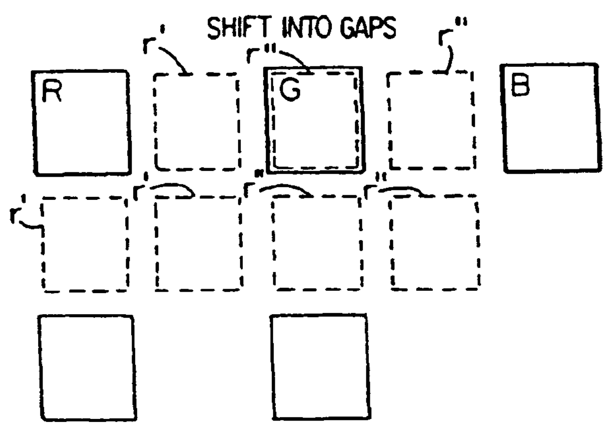

FIG. 15

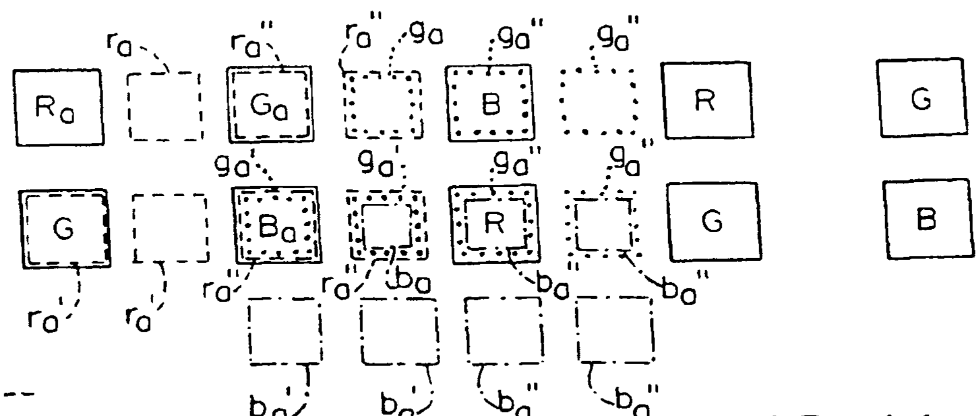

FIG. 14

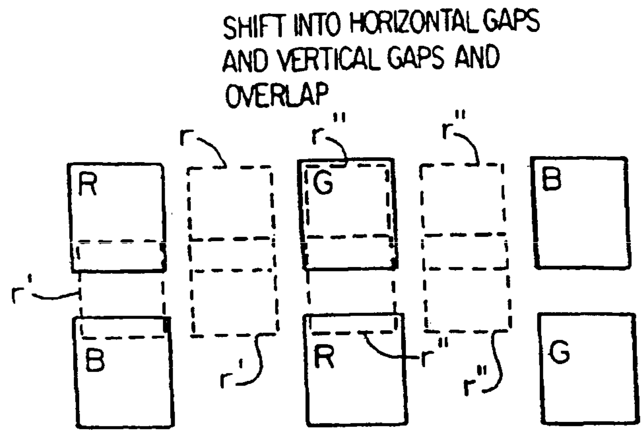

FIG. 16

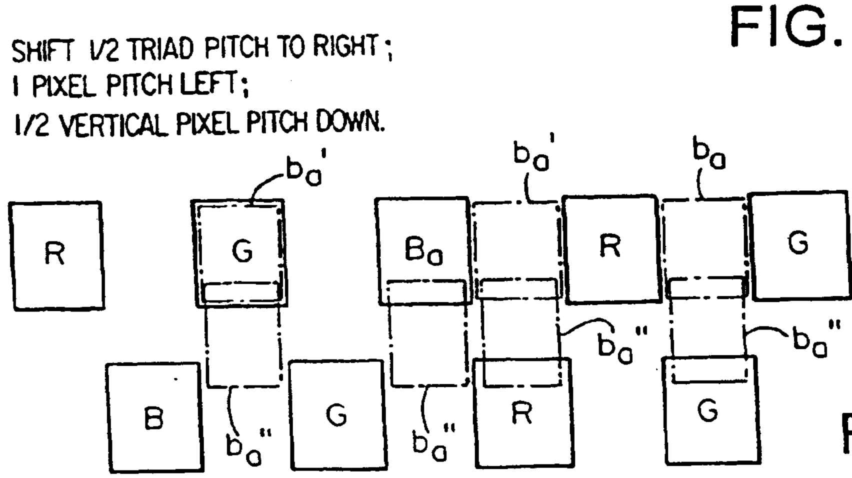

FIG. 17

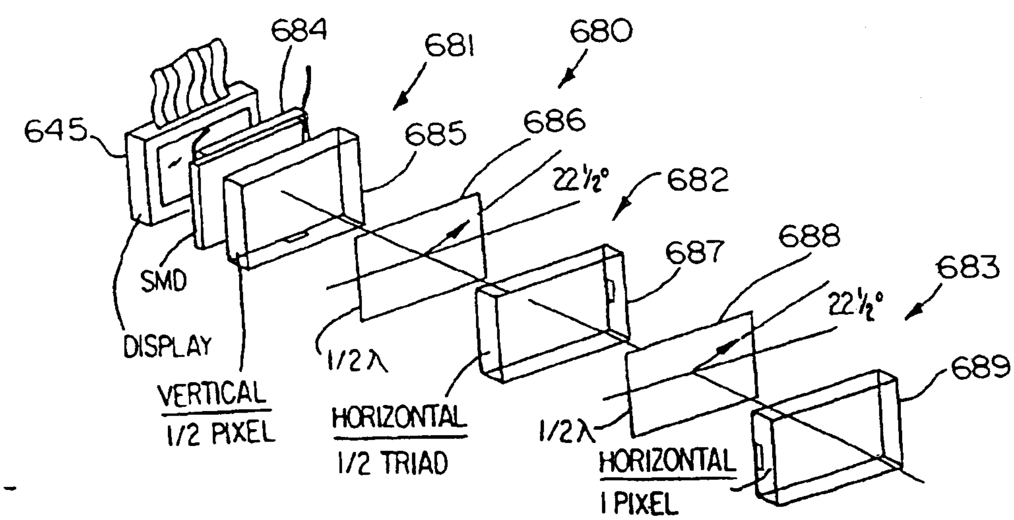

FIG. 18

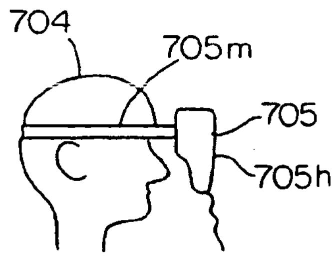
704
705m
705
705h

FIG. 19

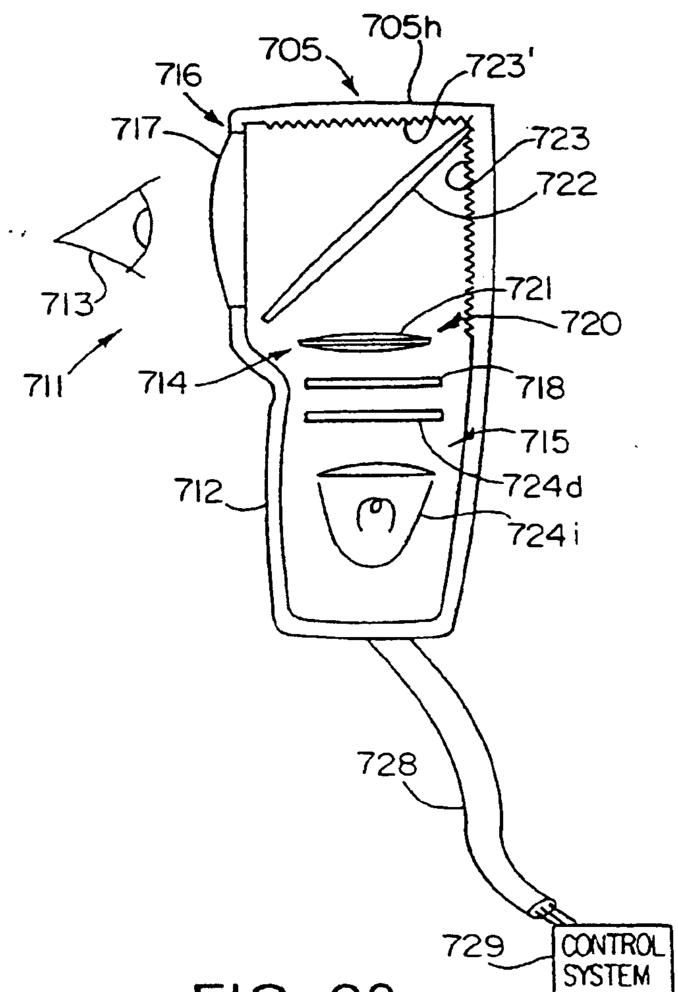
705h
705
716
723'
717
723
722
713
721
720
711
714
718
715
712
724d
724i
728
729
CONTROL SYSTEM

FIG. 20

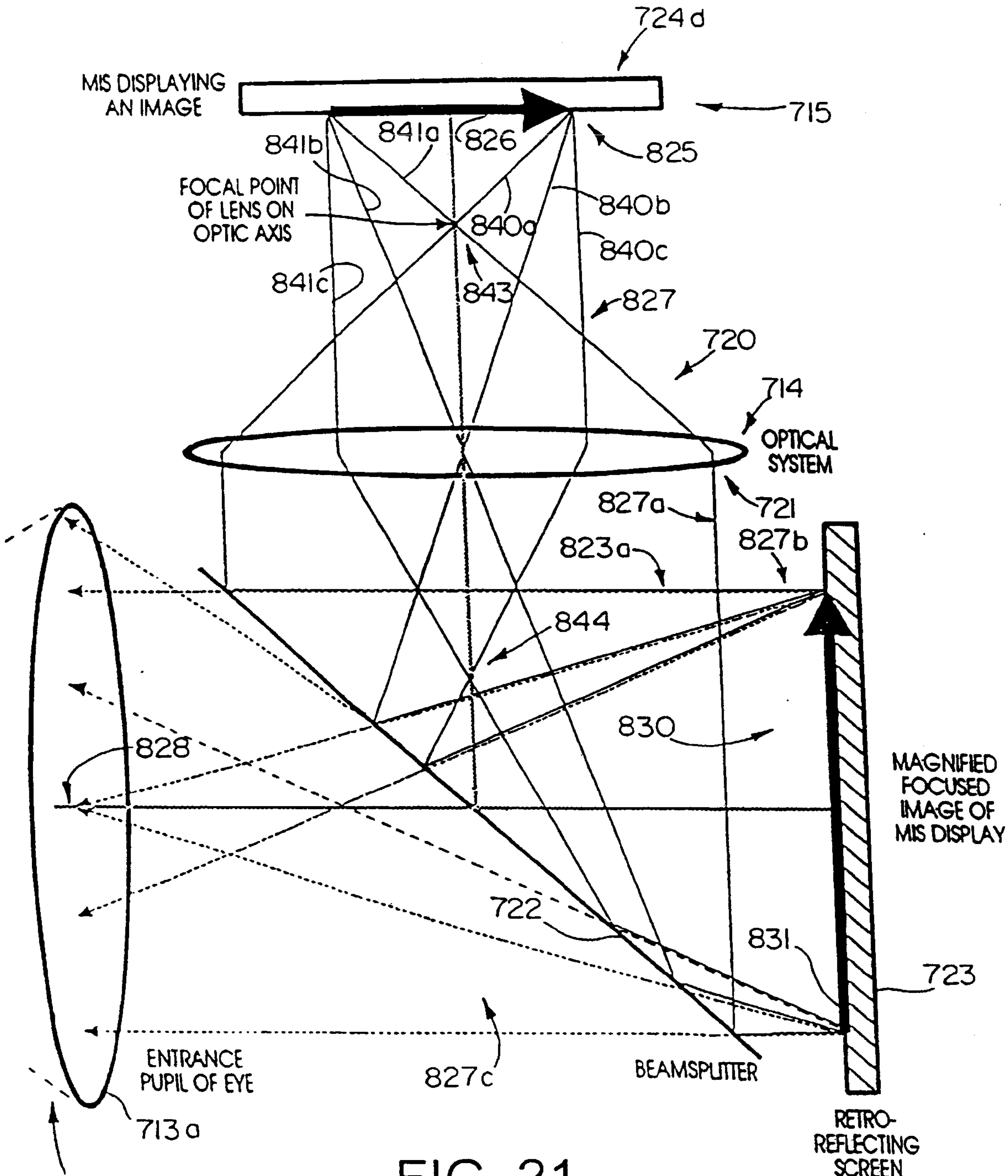
724d
MIS DISPLAYING AN IMAGE
715
841b
841a
826
825
FOCAL POINT OF LENS ON OPTIC AXIS
840b
840a
840c
841c
843
827
720
714
OPTICAL SYSTEM
827a
721
823a
827b
844
830
828
MAGNIFIED FOCUSED IMAGE OF MIS DISPLAY
722
831
723
ENTRANCE PUPIL OF EYE
827c
BEAMSPLITTER
RETRO-REFLECTING SCREEN
713a
713

FIG. 21

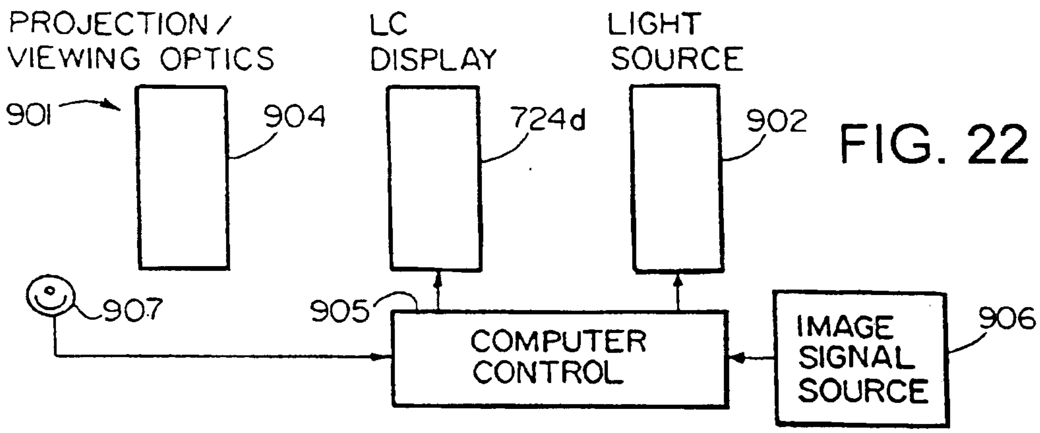

FIG. 22

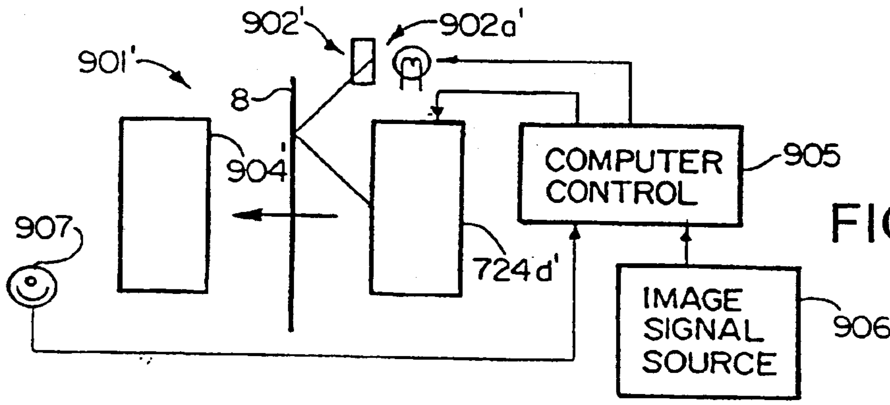

FIG. 23

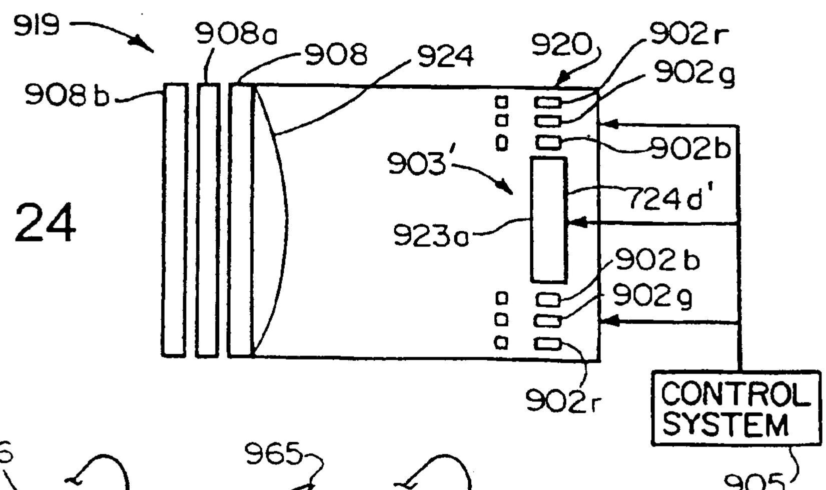

FIG. 24

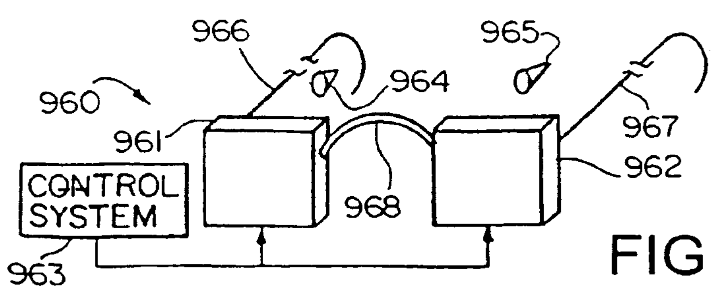

FIG. 25

A DOT MATRIX LCD AND THE SHADE OF GREY MEASURED AT SEVERAL PIXELS

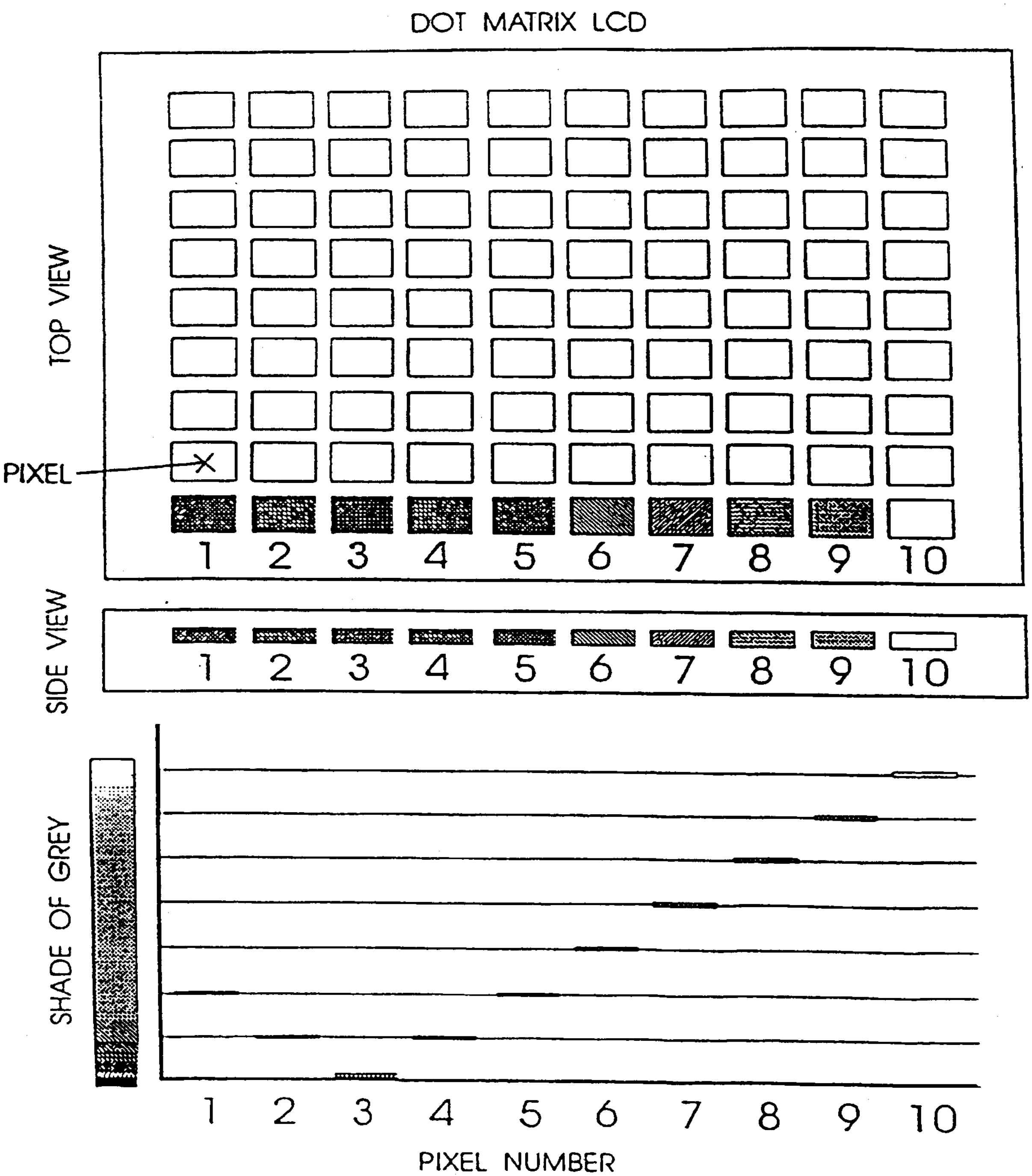

FIG. 26

SCENE CONTAINS A BRIGHT IMAGE BACK LIGHT IS AT A MEDIUM (NORMAL) ILLUMINATION LEVEL

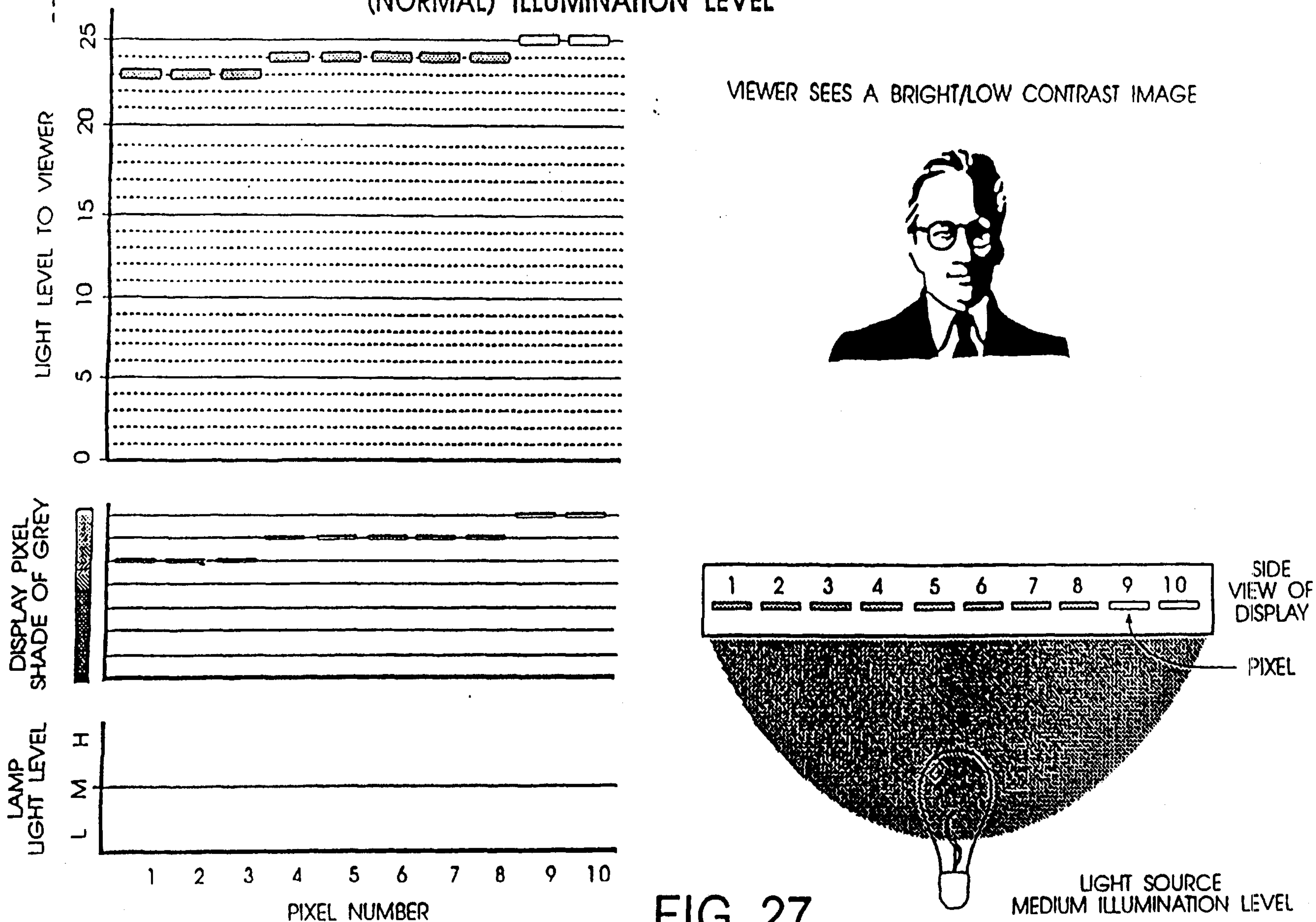

FIG. 27

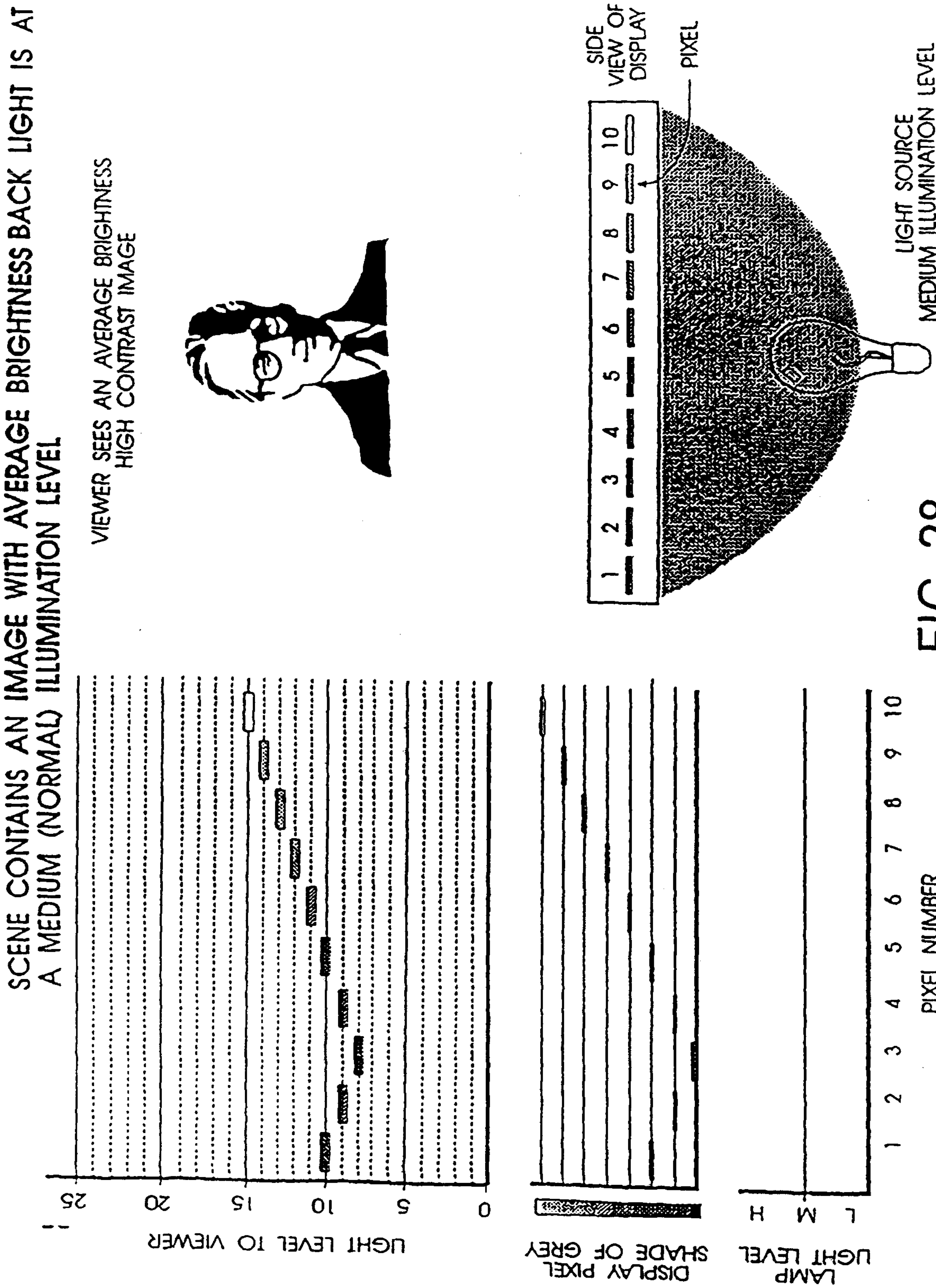
SCENE CONTAINS AN IMAGE WITH AVERAGE BRIGHTNESS BACK LIGHT IS AT A MEDIUM (NORMAL) ILLUMINATION LEVEL
VIEWER SEES AN AVERAGE BRIGHTNESS HIGH CONTRAST IMAGE
LIGHT LEVEL TO VIEWER
0
5
10
15
20
25
DISPLAY PIXEL SHADE OF GREY
LAMP LIGHT LEVEL
L
M
H
PIXEL NUMBER
1 2 3 4 5 6 7 8 9 10
SIDE VIEW OF DISPLAY
PIXEL
LIGHT SOURCE MEDIUM ILLUMINATION LEVEL

FIG. 28

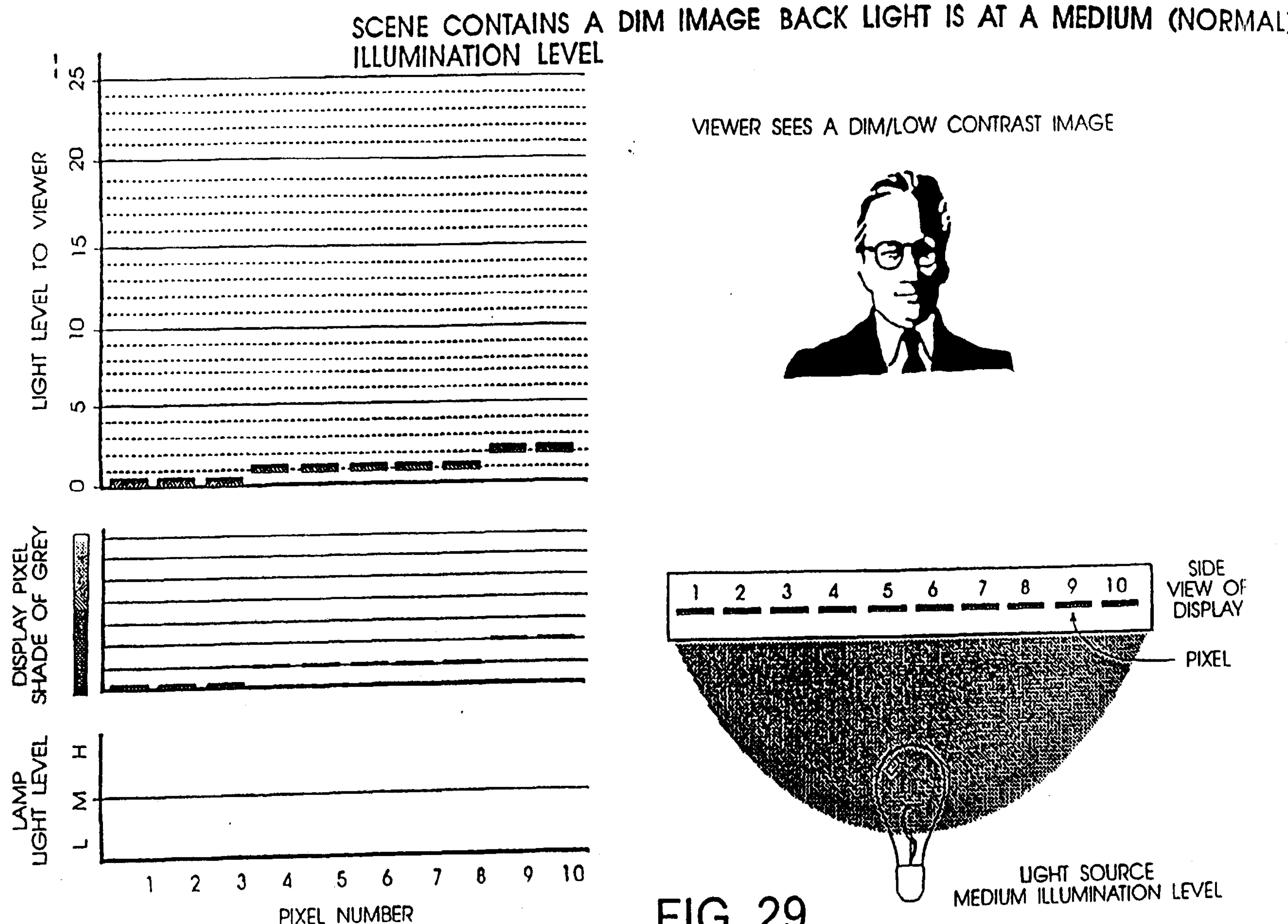
SCENE CONTAINS A DIM IMAGE BACK LIGHT IS AT A MEDIUM (NORMAL) ILLUMINATION LEVEL
LIGHT LEVEL TO VIEWER
0
5
10
15
20
25
DISPLAY PIXEL SHADE OF GREY
LAMP LIGHT LEVEL
L
M
H
1 2 3 4 5 6 7 8 9 10
PIXEL NUMBER
VIEWER SEES A DIM/LOW CONTRAST IMAGE
1 2 3 4 5 6 7 8 9 10
SIDE VIEW OF DISPLAY
PIXEL
LIGHT SOURCE MEDIUM ILLUMINATION LEVEL

FIG. 29

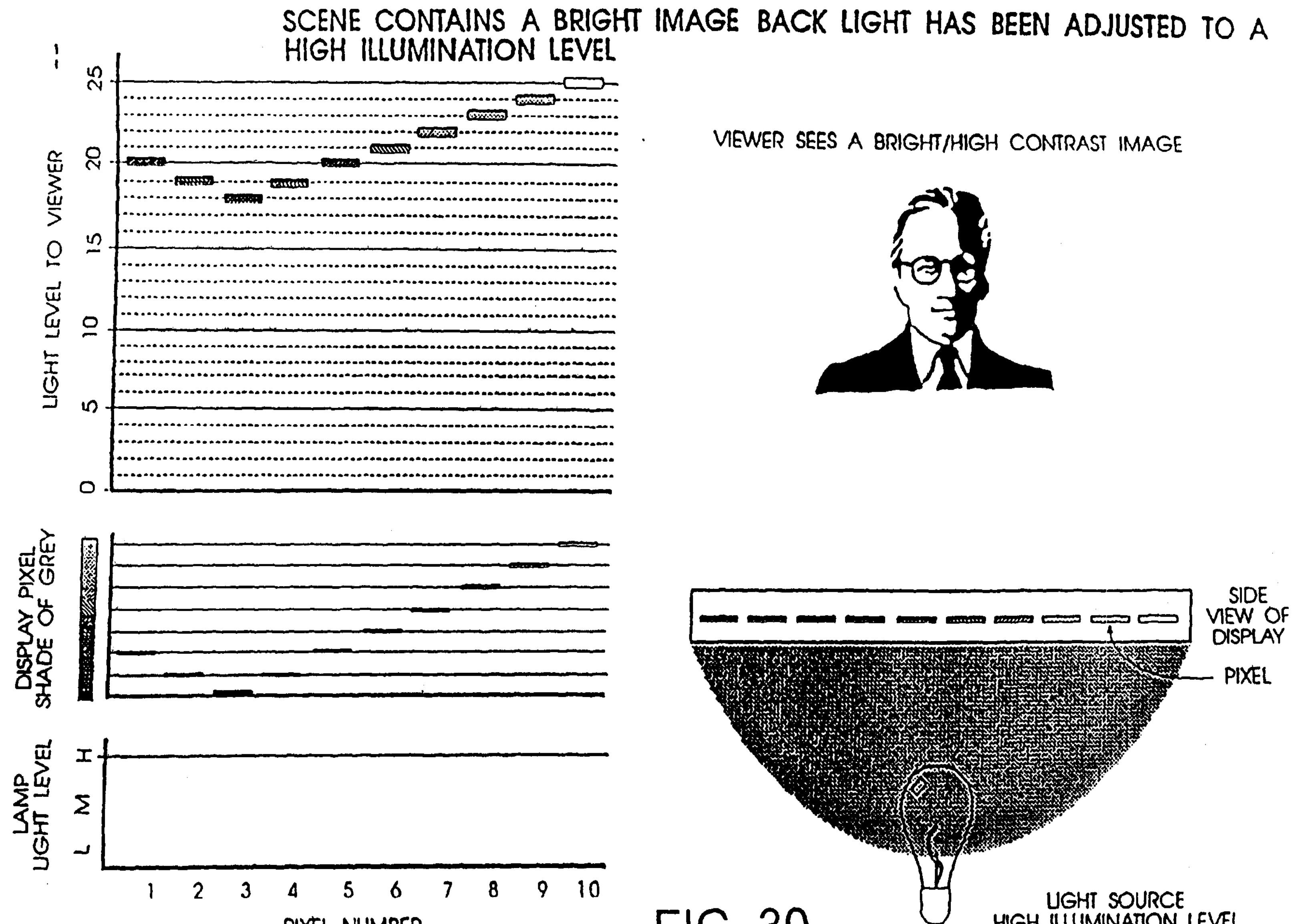
SCENE CONTAINS A BRIGHT IMAGE BACK LIGHT HAS BEEN ADJUSTED TO A HIGH ILLUMINATION LEVEL
LIGHT LEVEL TO VIEWER
0
5
10
15
20
25
DISPLAY PIXEL SHADE OF GREY
LAMP LIGHT LEVEL
L
M
H
1
2
3
4
5
6
7
8
9
10
PIXEL NUMBER
VIEWER SEES A BRIGHT/HIGH CONTRAST IMAGE
SIDE VIEW OF DISPLAY
PIXEL
LIGHT SOURCE HIGH ILLUMINATION LEVEL

FIG. 30

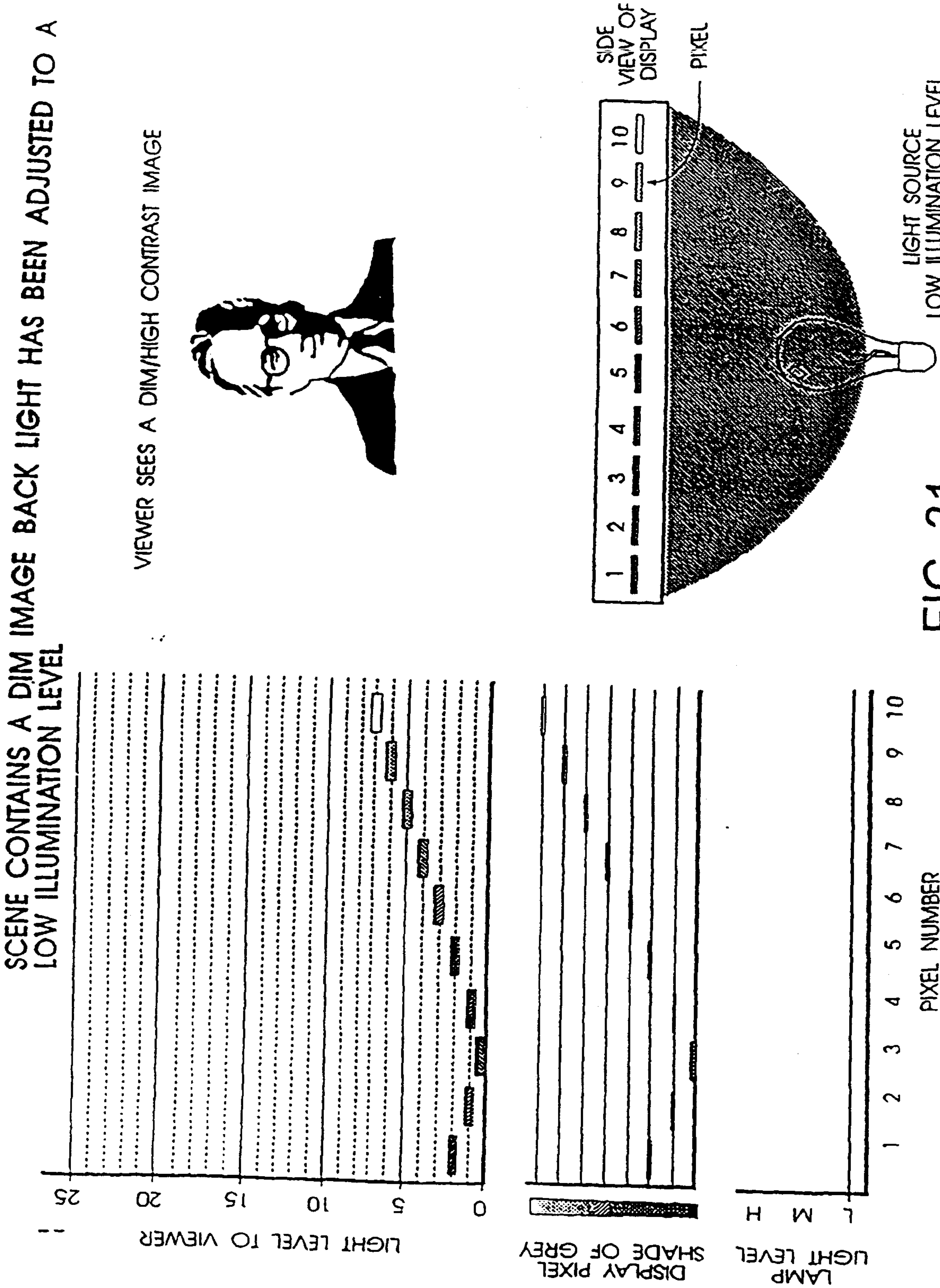
SCENE CONTAINS A DIM IMAGE BACK LIGHT HAS BEEN ADJUSTED TO A LOW ILLUMINATION LEVEL
VIEWER SEES A DIM/HIGH CONTRAST IMAGE
SIDE VIEW OF DISPLAY
PIXEL
LIGHT SOURCE LOW ILLUMINATION LEVEL
1 2 3 4 5 6 7 8 9 10
LIGHT LEVEL TO VIEWER
0 5 10 15 20 25
DISPLAY PIXEL SHADE OF GREY
LAMP LIGHT LEVEL
L M H
PIXEL NUMBER

FIG. 31

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 12 2867

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	US 5 122 791 A (GREEN IAN M ET AL) 16 June 1992 (1992-06-16) * column 3, line 1 - line 8 * * column 3, line 45 - column 6, line 6 * * column 7, line 42 - line 60 * ---	1-17,19, 20	G09G3/34 G09G3/36
X	WO 94 10675 A (KAVANAGH MARTIN ;RANK BRIMAR LTD (GB)) 11 May 1994 (1994-05-11) * page 9, line 10 - page 13, line 17 * * page 15, line 11 - line 18 * ---	1-11,19, 21	
P,X	US 5 359 345 A (HUNTER C ERIC) 25 October 1994 (1994-10-25) * column 5, line 5 - column 6, line 59 * -----	19,20	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)
G09G

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27 April 2001	Amian, D

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 00 12 2867

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

27-04-2001

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5122791 A	16-06-1992	AT 89426 T	15-05-1993
		AT 79684 T	15-09-1992
		CA 1294720 A	21-01-1992
		CA 1295062 A	28-01-1992
		DE 3781231 A	24-09-1992
		DE 3781231 T	11-03-1993
		DE 3785813 A	17-06-1993
		DE 3785813 T	11-11-1993
		EP 0261896 A	30-03-1988
		EP 0261897 A	30-03-1988
		ES 2040258 T	16-10-1993
		ES 2033863 T	01-04-1993
		GR 3005490 T	24-05-1993
		JP 63278098 A	15-11-1988
		JP 2567871 B	25-12-1996
		JP 63113426 A	18-05-1988
WO 9410675 A	11-05-1994	NONE	
US 5359345 A	25-10-1994	US 5724062 A	03-03-1998

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82